

# **ITALIAN MOUNTAIN GEOLOGY**

**PART III**

**CENTRAL AND SOUTHERN ITALY**

BY

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LONDON

WHELDON & WESLEY, LTD.

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# ITALIAN MOUNTAIN GEOLOGY.

PART III.

CENTRAL AND SOUTHERN ITALY.

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- \*1917-18. Italian Mountain Geology, Parts I and II. Dulau & Co.  
(The Moraine Walls and Lake Basins of Northern Italy. The Piedmontere Alps, Ligurian Apennines, Carrara Mountains, Sub-apennines, Volcanic Groups of ditto; the Geol. Structure of Elba.)
1918. The Ruitor Glacier Lakes, Grajan Alps: "Journ. R. Sc. Geogr. Soc."
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1919. The Ancient Sea and Lake Basins of Central Italy: idem.

\* Review in Magazine of R. Scottish Geogr. Society, October, 1918: "The volume is an indispensable textbook of Italian mountain geology and one which contains also much that is of interest to the geographer."

# ITALIAN MOUNTAIN GEOLOGY.

## PART III.

THE GRAN SASSO D'ITALIA GROUP, ABRUZZI,  
CENTRAL APENNINES.

THE VOLCANOES OF CENTRAL AND SOUTHERN ITALY.

BY

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1923

STEPHEN AUSTIN AND SONS, LTD.  
PRINTERS, HERTFORD.

554.5  
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Geology

## PREFACE.

THE first two parts of this work, published in 1917 and 1918, having dealt with the Mountain Geology of Northern Italy, i.e. the Piedmontese Alps, the Ligurian Apennines, the Subapennines, and Elba, the present, third, self-contained, and concluding Part embraces the most conspicuous regions of Central and Southern Italy, i.e. the Gran Sasso d'Italia Group of the Abruzzi or Central Apennines, the great volcanic groups of the Roman and Neapolitan areas, and an exhaustive study of Mount Etna, Sicily.

Like the previous Parts I and II, so also is the present Part III the outcome of extensive personal study and observation during ten years of professional scientific work in various parts of Italy. The synthetic geological descriptions of the different regions are supplemented by petrographic notes and tables of chemical analyses of the principal volcanic products. The illustrations comprise a series of sketch-maps and sections of the regions described, together with photographic reproductions of the whole volcanic area of the Gulf of Naples, including Somma-Vesuvius, the Bay of Pozzuoli, the Phlegræan Fields, and the Island of Ischia.

The present volume, Part III, is offered, as were the two earlier parts, to geologists, geographers, and to all lovers of science and nature, more especially to those interested in volcanic phenomena and in the beauty, grandeur, and infinite variety of Italian mountain scenery, replete, moreover, at every turn with historical associations. The work is inspired by my great affection for Italy. *D'antico amor*, as Dante says, *sento la gran potenza*.

C. S. DU RICHE PRELLER.

61 MELVILLE STREET, EDINBURGH.  
September, 1923.



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# I.

## The Gran Sasso d'Italia Group, Abruzzi, Central Apennines.

I. GENERAL FEATURES.

II. PHYSICAL FEATURES.

ILLUSTRATIONS, FIGS. 1, 2, 3.

III. GEOLOGICAL FEATURES.

IV. CONCLUSION.

### I. GENERAL FEATURES.

THE mountain chain known as the Abruzzi<sup>1</sup> forms the link between the Umbrian and Neapolitan Apennines. Like these, it is built up of a series of more or less parallel ranges of hills trending north-west to south-east, and separated by valleys running in the same direction. These parallel ranges comprise, in eastward succession from Rome, the Sabine and Penestrini (Latian), the Simbruini, and the Morrone and Mte. Velino Hills, which successively increase in altitude from 600 to 1,400 and over 2,000 m. respectively. The fourth and culminating range is the Gran Sasso massif, which attains 2,900 m. above sea-level. Its crest line lies 140 km. from the Tyrrhenian and 30 km. from the Adriatic Sea. This massif, falling abruptly on both its versants, i.e. towards Aquila on the east and towards Teramo on the west, comprises the highest points of the divide between the two great watersheds not only of the Abruzzi, but of the entire chain of the Apennines, of which it constitutes the central section.<sup>2</sup> Its commanding position, as well as its remarkable physical and geological features, have exercised a peculiar fascination ever since it was first ascended and in its general outline examined by O. Delfico in 1794.

To the north-west of the Gran Sasso the crest line of the Abruzzi is formed by Mte. Sorrano (2,450 m.) and Pizzo di Sevo (2,016 m.) abutting against the Sibillini Mountains, whose highest point is Mte. Vettore (2,478 m.) above Ascoli Piceno ; to the south-east by

<sup>1</sup> The name Abruzzi is by some regarded as a corruption of " Pretutium ". In the present writer's view it is much more likely to be derived from " ab " (down, away) and " ruzzolare " (to roll), viz. from the tendency of large detritic masses to roll or slide down the mountain sides. Thus " Ruzzo " is the name of a ravine, " Ruzza " that of a mountain of the Gran Sasso massif, both eminently detritic.

<sup>2</sup> Geographically the Abruzzi, which culminate in the Gran Sasso, comprise the three provinces of Teramo, Chieti, and Aquila, 12,148 sq. km. in aggregate area. The mountain range extends from the River Tronto (Prov. of Teramo) to the Sangro (Prov. of Chieti), both on the Adriatic versant. It lies exactly midway of the Apennines, i.e. 500 km. from their northern and southern extremities. Hence the strictly correct designation of " Central Apennines ", though, by extension, the term is often held to include also the Sibillini as well as Umbrian or Roman sections of the mountain chain.

the massif of La Majella which culminates in Mte. Amaro (2,795 m.) above Sulmona. The total length of the crest line is 100 km. Contrasting with the long-stretched valleys on the Tyrrhenian side, the valleys on the Adriatic versant are all short, deep-cut, and run transversely, i.e. at right angles to the trend of the mountain chain. The Gran Sasso massif proper is bounded inland, on the north-west, by the River Vomano which rises near the western extremity of the group on the flanks of Arco Cigliano at 1,300 m. altitude and drains into the Adriatic; on the Tyrrhenian versant its boundary is the River Aterno, which has its source near Montereale at 1,000 m. altitude, and thence flows south-east along the base of the massif past Aquila (615 m.), till it reaches the remarkable Pleistocene lake basin of Sulmona (400 m.) in the very heart of the Abruzzi. At Rajano, in that basin, the Aterno was banked and abruptly, at right angles, deflected north-east by the River Gizio from the south. United, they intersect the main range by the steep and narrow defile of Popoli (270 m.), whence, taking the name of River Pescara, they drain through the broadening alluvial valley of Chieti to the sea.

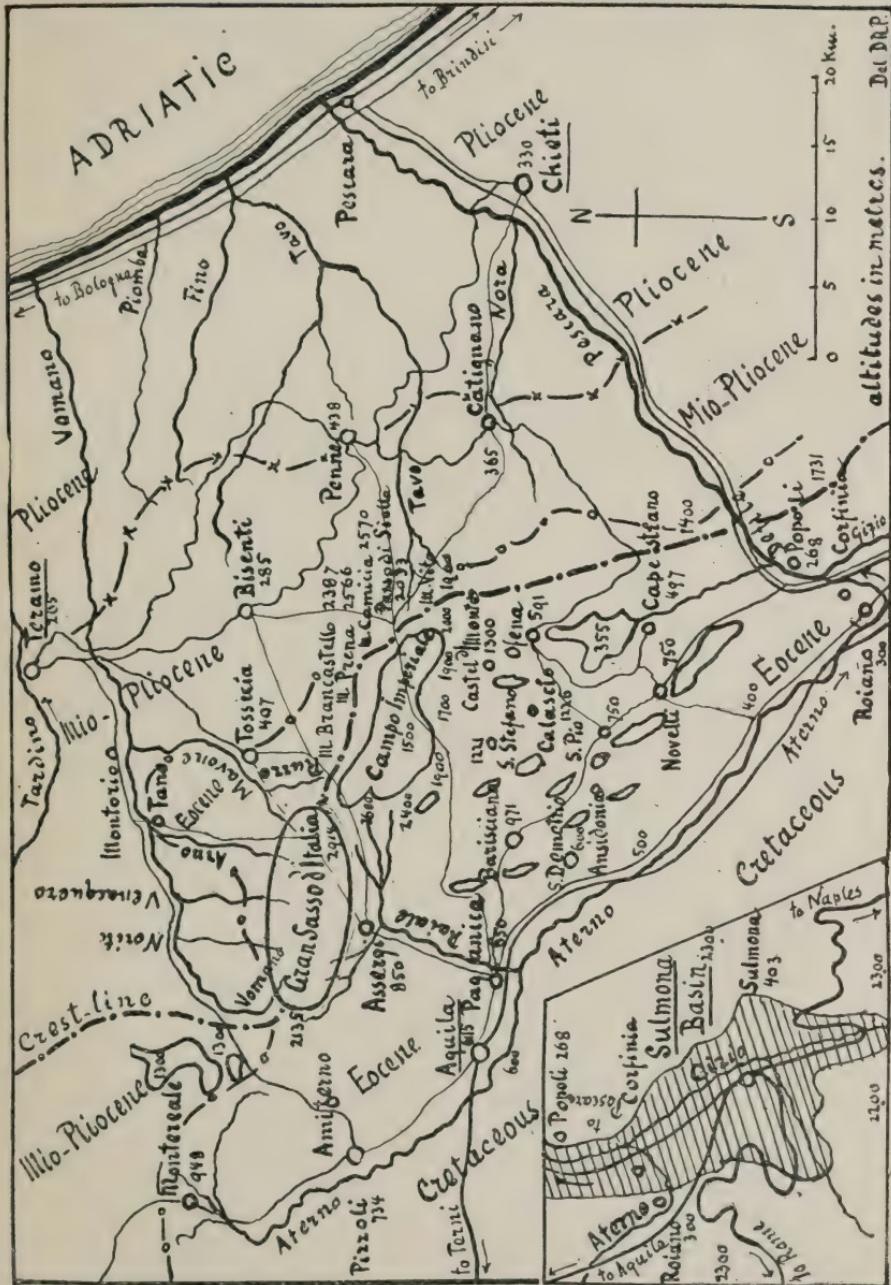
Between the two boundary rivers, the Vomano and the Pescara, numerous torrents, the Mavone, Tavo, Fino, and others, descend from the massif to the sea, the rainfall and drainage being much greater, and consequently erosion and denudation much more active, on the Adriatic than on the Tyrrhenian versant; so much so that the Adriatic side of the massif towards Teramo is destined to wear away to a cirque. On the other, or Aquila side, the massif proper is drained only by the streams forming the torrent Rajale, which descends about midway and discharges into the Aterno east of Aquila.<sup>1</sup> Oak, beech, and pine plantations extend up the south flank above Assergi to 1,500 m., green slopes up to over 2,000 m. altitude. The mountain is now ascended without difficulty on either side, the ascent from Teramo being the steeper, that from Aquila the more convenient, i.e. by the Rajale ravine from Paganica (650 m.) to Assergi (847 m.), and thence either by the Portella Pass (2,236 m.) and the old Rifugio (2,200 m.), or by the new Rifugio Duca d'Abruzzi (2,410 m.) to Corno Grande, the summit (2,914 m.).

## II. PHYSICAL FEATURES.

The Gran Sasso massif exhibits, more especially in its upper parts and its central group along the crest line, extraordinary effects of compression, corrugation, contortion, and upward thrust of its strata, later followed by remarkable fractures, internal subsidences, and other phenomena akin to those of the Illyrian and Istrian

<sup>1</sup> A fine mountain road, 60 km. in length, runs over the divide between the rivers Aterno and Vomano by the Capanello Pass (1,300 m.) on the western extremity of the massif, skirting the west flank of Mte. S. Franco. The road connects Aquila with Teramo, the chief cities of the two provinces respectively.

The Gran Sasso d'Italia Group, Abruzzi, Central Apennines.

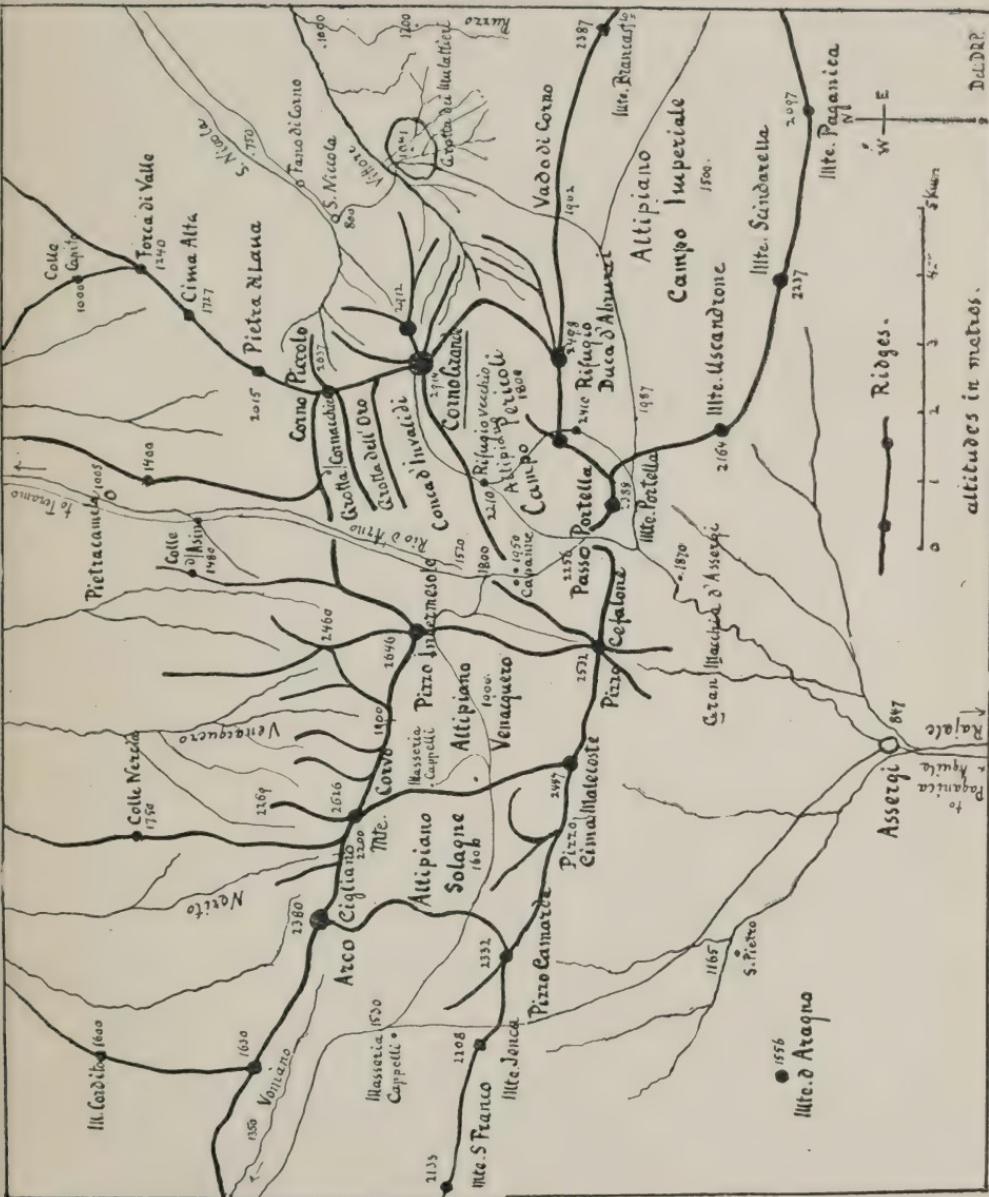


Carso and also of the Swiss Jura. From Mte. S. Franco (2,135 m.) at the western extremity the crest line runs eastward to Mte. Jenca (2,206 m.), and thence divides into two precipitous parallel ridges 8 km. in length and 2 km. apart, concavely curved towards the Adriatic and forming an arc of 60 degrees. These two ridges constitute the central group of the massif. The highest points of the inner, or northern, principal ridge are, from west to east, Arco Cigliano (2,380 m.), Mte. Corvo (2,626 m.), Pizzo Intermesole (2,646 m.), and the summit, Corno Grande (2,914 m.), with its satellite, Corno Piccolo (2,637 m.), seated on its north flank. The outer or southern ridge comprises as its highest points Pizzo di Camarda (2,637 m.), Cima delle Malecoste (2,447 m.), Pizzo Cefalone (2,532 m.), and Mte. Portella (2,388 m.).

These two ridges, with their imposing domes and peaks culminating in the "horn" pyramid or "gran sasso" of Corno Grande, 300 m. higher than all the rest, are linked by four remarkable cross ridges: the first, on the west, connecting Arco Cigliano with Pizzo Camarda; the second, linking Mte. Corvo with Cima delle Malecoste; the third, midway, connecting Pizzo Intermesole with Pizzo Cefalone; and the fourth, on the east, linking Corno Grande with Mte. Portella. Between these four cross ridges lie the three self-contained altipiani or trough-basins of Solagne, Venacquero, and Campo Pericoli, with their lowest points at 1,600, 1,900 and 1,800 m. altitude respectively, i.e. about 800 m. below the encircling crest walls. These troughs, each about 2 sq. km. in area, are closed to the south, but each has a narrow eroded opening to the north or Adriatic versant into a precipitous gully or ravine, which formerly drained its respective altipiano.<sup>1</sup> The three exit gaps and ravines are respectively those of the torrents Nerito, Venacquero, and Arno. The most easily accessible and largest of the three basins is that of Campo Pericoli, over whose western extremity, i.e. the Portella Pass (2,236 m.), runs the mule-path of that name, which from here, i.e. on the Adriatic side, drops rapidly into the ravine of Rio d'Arno, a tributary of the Vomano. In the upper part of that ravine, at right angles to the same, lie in succession three other altipiani or troughs at 1,800, 1,500, and 1,400 m. altitude respectively: Conca degli Invalidi, in the gap between Pizzo Intermesole and Corno Grande; Grotta d'Oro, between the ridge of that name and Corno Piccolo; and Grotta delle Cornacchie, at the north base of Corno Piccolo. From the ravine the west flanks of Corno Grande and Corno Piccolo soar straight to a height of 1,000 m. at 30°, or 1 in 2.

Equally precipitous is the eastern flank of the Corno Grande pyramid, which, down to the Vado di Corno Pass (1,962 m.), is also 1,000 m. in height and 2 km. in length. From this point (2,000 m.) the crest of the massif runs east for 12 km., the highest points being

<sup>1</sup> The exit gaps were eroded when the floors of the troughs were considerably higher than at present. The gaps are being further deepened by the backward erosion of the torrents.



Mte. Brancastello (2,386 m.), Mte. Prena (2,566 m.), and Mte. Camicia (2,570 m.), whence it turns abruptly south to Mte. Siella (2,033 m.), Mte. Vito (1,907 m.), and Mte. Guardiola (1,528 m.), and then follows this direction at altitudes decreasing to 1,300 m., till it reaches the Popoli defile of the River Aterno (270 m.).<sup>1</sup>

Immediately south of the first part of this section, i.e. from Corno Grande to Mte. Camicia, lies another remarkable altipiano or subsidence trough, that of Campo Imperiale,<sup>2</sup> much more extensive than the six crestal basins. On the north it is bounded by the rampart just mentioned; on the east it is closed in by Mte. Siella and Mte. Vito; on the south by an uninterrupted chain of hills 1,700 to 1,900 m. in altitude; and at its western end by Mte. Paganica (2,007 m.), Mte. Scinderella (2,247 m.), Mte. Uscandrone (2,164 m.), and Mte. Portella (2,388 m.) previously mentioned. This elliptic old lake basin, whose extensive floor lies at 1,500 m. altitude, or from 400 to 1,000 m. below the encircling mountains, covers 16 by 3 km., or about 50 sq. km., and is completely closed in without any apparent exit of surface drainage. The drainage must, therefore, sink into the absorbent soil and thence into underground passages.

The outstanding feature of this and the six crestal altipiani from 300 to 1,000 m. in depth, in which, more especially in the latter, snow lies even in summer, consists in the rounded hillocks and the pits, funnels, or dolines so characteristic of the Carso and also of the Swiss Jura. In the Gran Sasso massif, these phenomena cannot be ascribed to the action of glaciers, although glacial evidence is not wanting in another form. They can only be due, as they are in typical Carso regions, to fractures, subsidences, underground hollows and gaps formed by percolating and circulating drainage water, and superficially to hydration, notably through the pressure and dissolving action of melting snow. The narrow, rugged, and sharp-edged northern outlet gaps of the crestal troughs are all V-shaped, i.e. of fluviatile origin. In the present writer's view they absolutely preclude the action of large glaciers, which would have abraded and widened those gaps and the ravines beyond them to the usual ice-worn U-shape.

The orographic and tectonic characteristics of the Gran Sasso group as two great parallel, anticlinal ridges with a syncline between them, strikingly resemble those of the Apuan Alps or Carrara

<sup>1</sup> The Aterno valley boasts the ruins of the ancient cities and cyclopean walls of Corfinium near Popoli, Sulmo near Sulmona (the birthplace of Ovid, 43 B.C.), Ansidonia 18 km. S.E. of Aquila, and Amiternum 8 km. N.W. of Aquila (the birthplace of Sallust, 86 B.C.). The whole district, occupied by the Sabines and Paeligui, was called ancient "Italica", and came under Roman dominion about 90 B.C.

<sup>2</sup> Campo Imperiale or dell' Imperatore is, like other local designations, associated with Frederic II, who was born at Tesi, near Ancona, in 1194, and founded Aquila in 1240. It was partially destroyed by Manfred in 1259 and rebuilt by Charles of Anjou. Among its visitations are those of not infrequent earth-shocks, due to its lying on the line of a great fracture-fault.

Mountains, a fact which appears not to have been pointed out before. Both ranges, rising in close proximity to the sea, exhibit the imposing alpine features of great arched and peaked walls, an effect which in the Gran Sasso group is enhanced by Corno Grande itself, towering from 300 to 1,000 m. above all the surrounding mountains of the Abruzzi.

### III. GEOLOGICAL FEATURES.

No less remarkable than the orographic and tectonic features of the Gran Sasso massif are those of its closely related geological characteristics. The latter subject has produced a fairly extensive bibliography since Delfico's ascent in 1794<sup>1</sup> brought the mountain into prominent notice. Among the more recent stratigraphical and palaeontological contributions are notably Baldacci and Canavari's of 1884; Sacco's Memoir of 1909; Casetti's and Parona's papers of 1908–10; and Chelussi and Clerici's of 1901–3.<sup>2</sup>

The geological formations of the massif, like those of the Central Apennines generally, comprise Mesozoic beds as substrata, overlain and covered all round by an Eocene mantle up to 800 m. in thickness, which on the Adriatic versant is overlain by a great Mio-Pliocene, and on the lower slopes by a Pliocene belt. Pleistocene, more recent Quaternary, and alluvial deposits are scattered over both versants. It is noteworthy that the Aterno valley throughout its length down to the Sulmona basin<sup>3</sup> lies along a great fracture caused by the Eocene strata of the massif impinging upon the Cretaceous strata of the Mte. Velino group. Hence the liability of the valley to seismic disturbances.

The Mesozoic formations of the massif are exposed along the crest of the central group and in several considerable outcrops on the Aquia versant. Together with the Tertiary formations, they present the following downward sequence:—

*Pliocene*: Grey marl and conglomerates.

*Mio-Pliocene*: Banks of sandstone and grey marl.

<sup>1</sup> O. Delfico, *Osservazioni su di una piccola parte degli Apennini, 1794; Ascensione del Gran Sasso, 1796.*

<sup>2</sup> L. Baldacci and M. Canavari, "La Regione centrale del Gran Sasso d'Italia": Boll. R. Com. Geol., 1884. E. Clerici, "Fenomeni carsici-glaciali Apenn. Aquil.": Atti Soc. It. Sc. Nat., 1901. T. Chelussi, "Conca Aquilana": ibid., 1903. F. Sacco, "Gli Abruzzi": Boll. Soc. Geol. It., 1907; "Il Gruppo del Gran Sasso d'Italia": R. Acc. Sc. Torino, 1909. C. F. Parona, "Dati Paleontologici sui terreni mesozoici dell'Abruzzo": Boll. R. Com. Geol., 1908. M. Casetti, *Struttura geologica della regione orientale del G. S. d'Italia*, ibid., 1910.

<sup>3</sup> The Sulmona basin (400 to 300 m.), a triangular trough, 20 by 10 km., entirely covered by Pleistocene deposits, is shut in on three sides by the Eocene, Cretaceous, and Liassic limestone formations of the Majella, Mte. Rotella, and Mte. Firente groups, over 2,000 m. in altitude. It constituted a large lake, owing to the Aterno and the Gizio flowing in from opposite directions, till an outlet to the Adriatic was eroded through the Popoli defile. Sulmona is the junction of the four main lines of railway of the Abruzzi, i.e. from Naples, Rome, Terni, and Pescara, the first three of which descend into the basin by steep gradients.

*Eocene, Upper* : Greenish to reddish, marly and schistose limestone.

*Eocene, Lower* : Whitish to greenish, compact nummulitic limestone.

*Cretaceous* : White, grey to yellowish subcrystalline limestone

*Lias, Upper* : Grey, nodulous limestone. *Middle* : Pale reddish subcrystalline limestone. *Lower* : White and grey crystalline dolomitic limestone.<sup>1</sup>

*Infraceras (Rhætian)* : Cavernous limestone.

*Upper Trias* : White and pale grey dolomitic granular and saccharoidal limestone.

In the main the limestone formations, differentiated according to their superposition and their characteristic fauna fossils,<sup>2</sup> overlie each other conformably except in the crestal part of the group. Between the Eocene and the Mio-Pliocene formations occurs a hiatus, the Lower and Middle Miocene proper having, as in the Tuscan Apennines, been a period of potent erosion which left only isolated patches of that formation. Consequently, the Upper Miocene and its transition to Pliocene appear transgressively on the Eocene, but pass conformably to Pliocene proper.

The Gran Sasso group does not, in its stratigraphical sequence, differ materially from the neighbouring Sibillini and Majella massifs and other groups of the Abruzzi, but exhibits it in the accentuated form of much greater elevation, larger masses, and of acute folding and faulting on a much larger scale. Notably is this the case in the central group where, owing to the sharp curvature of the axis, the Mesozoic formations have been thrust up through the Tertiary mantle and so sharply folded that they are totally reversed in form, not only outcrops, but the highest peaks of the whole group.

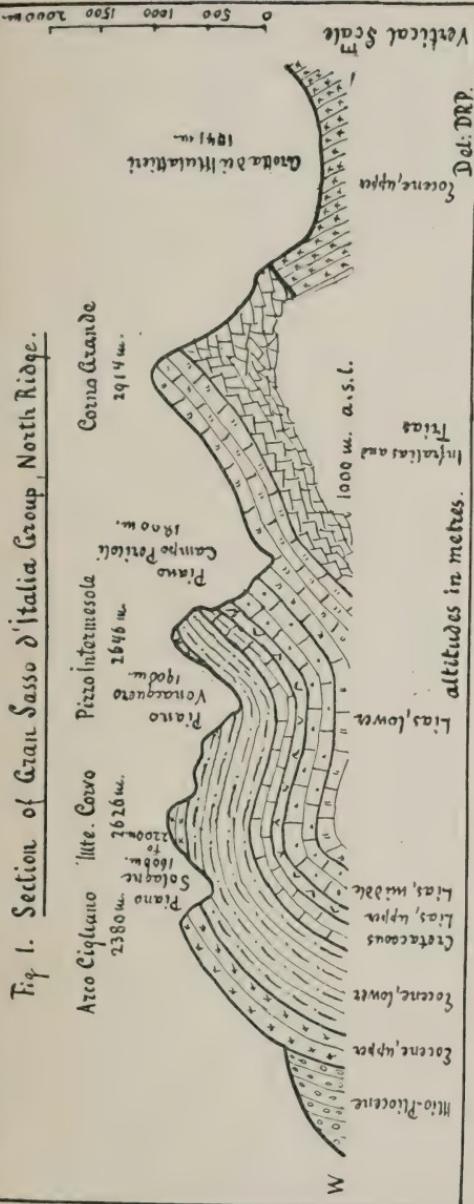
Following the crest-line eastward from Mte. S. Franco and Mte. Jenco, the greatly folded Eocene mantle forms the domal masses of Arco Cigliano and Mte. Corvo, separated by the deep exit gap of the Solagne trough. Between Mte. Corvo and Pizzo Intermesole the Eocene strata are again cut by the exit gap of the second or Venacquero trough, after which they are abruptly raised at an angle of 30 degrees to form the summit of the latter peak. Consequently, on its east flank are exposed, and raised at the same angle, the underlying Cretaceous and Liassic beds, which are cut by the exit gap of the third or Campi Pericoli trough between Pizzo Intermesole and Corno Grande. On the precipitous west flank of the latter the Lower Liassic strata, raised to an angle of 30°, are exposed to the whole height of 1,000 m. and form the summit of the great pyramid to a thickness of 300 m. On the east flank of the pyramid, below the Lias, appear the conformably subjacent Infrac-

<sup>1</sup> The composition of the dolomitic limestone is CaO, 49.42 per cent; MgO, 48.20 per cent; SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub>, 2.38 per cent = 100 per cent.

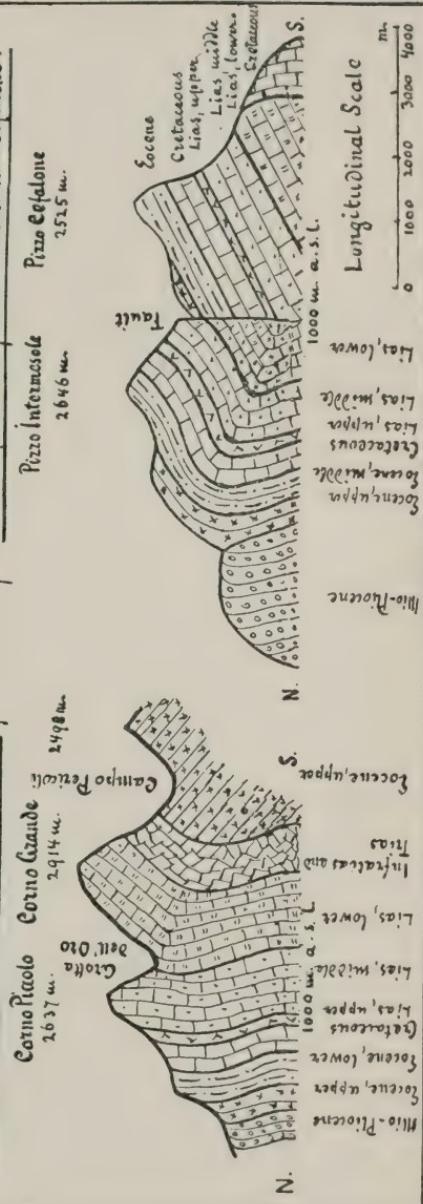
<sup>2</sup> The fossil fauna of the Gran Sasso massif has been described by Canavari, Parona, and others, op. cit.

sections of the Central Group, Sasso d'Italia, Abruzzi.

Hig. 3.



Section of Cerro Piccolo to Cerro Grande. Fig. 2.



Liassic and Upper Triassic dolomitic strata, here no less than 700 m. in thickness down to the base, where they appear in unconformable and transgressive contact with the Eocene mantle.

Equally striking phenomena of inverted folding and upward thrust are exhibited on the north flank of Corno Grande, as showing its close relationship to its offspring, Corno Piccolo. The summit of the latter is formed entirely of Middle Liassic limestone to a thickness of 500 m. down to the point of its contact with the Lower Lias of Corno Grande. Both these strata are here folded back and raised almost upright, and the same applies to the Upper Liassic, Cretaceous, Eocene, and Mio-Pliocene strata which form the lower north flank of Corno Piccolo in totally reversed sequence. Similar folding and reversal appears in the great cross ridge between Pizzo Intermesole and Pizzo Cefalone, where a great fault has so dislocated the whole series of formations that those of the former peak appear 500 m. above those of the latter. At the northern base these upraised formations are in unconformable contact with the Mio-Pliocene sandstone belt, at the southern base with the Cretaceous limestone banks above Assergi, i.e. in both cases in reversed order. All these phenomena of a great folding and reversing of the Mesozoic strata north-east and north to south-east and south in unconformable contact with the Tertiary formations show that the uprise took place in post-Pliocene, i.e. early Quaternary times.

To the east of Corno Grande the Eocene limestone mantle extends, according to Sacco, uninterruptedly to Mte. Camicia, and thence, together with several large Cretaceous areas, all the way south to the Popoli defile of the Aterno. This whole eastern part of the massif has, however, been shown by Cassetti to exhibit, from among the Eocene, outcrops of indubitably Upper Triassic and large continuous masses of Liassic dolomitic and subcristalline, as well as Cretaceous limestone, which masses form a great part of the mountain belt encircling the altipiano of Campo Imperiale. This evidence, confirmed by Parona on palaeontological grounds, and previously adumbrated by Baldacci and Canavari, is the more important as Sacco, in the then uncertainty as to that sequence, assigned the lowest horizon of the Gran Sasso massif to Infracriass or Rhætian, to the exclusion of Trias proper. Other large banks and masses of the Mesozoic series in conformable sequence, denuded of the Eocene mantle, are exposed over distances of 10 to 12 km. on the southern slopes of the central group, notably in the Rajale valley below and above the altipiano of Assergi, and in the Aterno valley immediately north of Aquila, as well as higher up in the same valley immediately north of Pizzoli.

On the Adriatic versant the Eocene limestone formation, locally called *pietra gentile*, is in evidence north of the Gran Sasso group over an area of 12 by 8 km. as far as the Vomano Valley towards Teramo. With that exception, the Eocene and the underlying Mesozoic formations are transgressively overlain and covered by the

great belt of Mio-Pliocene sandstone and marl, up to 1,000 m. in thickness, and on the lower slopes down to the sea by Pliocene deposits of marl and conglomerates. The latter formation rises on the slopes up to 500 m., the former up to 1,000 m., and on the north flanks of the Gran Sasso group to 1,900 m. above sea-level. These altitudes afford conclusive proof that at the time of the general Pliocene subsidence and submergence of the land the central part of the Gran Sasso massif had already emerged from the sea as an island group, and that its further uprise took place, as previously mentioned, by folding and thrusting during the earth-movements of the early Quaternary period.

*Pleistocene Deposits.*—These deposits are of fluviatile, lacustrine and, in part, of glacial origin. The former, composed of terraces of gravel and conglomerates, are in evidence more especially on the southern versant of the massif in the old lake basins or altipiani of Campo Imperiale, of Assergi, and of the Aterno Valley in the extensive basin of Pizzoli, north-west of Aquila, in and around Aquila itself, and of Bariciano and S. Demetrio, south-east of Aquila. In Campo Imperiale they reach up to 1,600 m. in altitude. On the Adriatic side they cover most of the steep flanks of the lower valleys and upper ravines.

Glacial deposits occur on the Adriatic versant as morainic, detritic accumulations in the upper reaches of the Vittore and Ruzzo ravines east of Corno Grande and on the Aquila side in patches on the flanks and in the troughs of the crestal group where, e.g. in Campo Pericoli, striated and moutonné rocks have been met with. Glaciers, if any, must have been of very small extent; on the other hand, fields of nevé must have been, as they are now in winter, very extensive, filling the troughs and ravines and covering the domes and peaks up to their summits. The morainic deposits and erratic blocks are, therefore, essentially fluvio-glacial, in great part re-transported material. Large accumulations of such and other detritic material, swept down by torrents and avalanches, are piled up along, and encumber the foothills of the massif; Aquila itself is built on an extensive terrace of Pleistocene detritus.

*Alluvial Deposits and Carso Phenomena.*—These phenomena, already noticed in the great troughs of the crestal group of Gran Sasso, are abundantly in evidence also on the southern or Aquila versant down to the Aterno Valley. The troughs and basins are here embedded in the Eocene and Cretaceous limestone formations, where their floors are overlain by Pleistocene material, which is covered, in its turn, by alluvial deposits washed down from the encircling hills. They abound at all altitudes from 350 up to 1,500 m., at which elevation lies the largest, previously mentioned altipiano Campo Imperiale, composed of a series of interconnected “piani” or level expanses, among them the former Lake Racollo. An Eocene boss about midway marks an island in this altipiano, formerly an extensive lake basin.

South and south-east of that basin towards the Aterno Valley, near Popoli (270 m.), among the Cretaceous and Eocene hills of Castel del Monte, S. Stefano, Calascio, Ofena, and Capestrano, are embedded and scattered over twenty-five troughs and basins which exhibit all the Carso characteristics previously referred to in the central groups of Gran Sasso. Most of the basins, including the fine altipiani of S. Pio and Navelli (750 m.), are elongated, often aligned in succession with elliptic island bosses on the same axis, and all lie in a south-easterly direction towards the Aterno. They are undoubtedly former lake basins, dried up for want of exit drainage, which latter now exists only in the large "piano" of Capestrano at 350 m. altitude, by a stream draining into the Aterno near Popoli. The troughs, smaller and more circular, are all wholly closed in and either waterless or their floors are peaty, with occasional pools. Their drainage passes wholly underground, though in some cases it re-emerges at the lower levels of the foothills as excellent spring water. All these basins and troughs, for want of exit and erosion, have been and are still being lowered by hydration and solution. The Aterno Valley, too, was formerly a succession of lake basins, including those of Pizzoli, Aquila, Paganica, and St. Demetrio, at 700, 600, and 500 m. altitude, with island bosses.<sup>1</sup> The Carso phenomena of the Gran Sasso massif vividly recall those of the Swiss Jura.

The underground stratigraphical disturbances to which the Gran Sasso massif, in common with other parts of the Apennines, is peculiarly liable, find expression not only in Carso phenomena, but more especially along extensive faults and fractures in seismic convulsions such as the earthquake of 1703, which proved so disastrous to Aquila and the region around. Similar violent shocks occurred in the same and the following century down to 1887.<sup>2</sup>

#### IV. CONCLUSION.

The Gran Sasso group is, alike in its general, physical, and geological features, as unique in Central Italy as the Apuan Alps or Carrara Mountains are in the north. Linking the Umbrian and Neapolitan Apennines, it exceeds them both in the variety of its phenomena and the rugged grandeur of its crestal domes and peaks as the product of the great Quaternary earth-movements which raised it to a

<sup>1</sup> A number of similar basins lie north-west of Aquila in the upper drainage areas of the Aterno and Vomano, as well as south of Aquila towards the great reclaimed basin of Lake Fucino (700 m.).

<sup>2</sup> Since the great earthquake of 1703, Aquila has been visited, apart from minor disturbances, by severe earthquakes in 1750, 1762, 1786, 1803, 1850, and 1887. In the Sulmona basin, 50 km. south-east of Aquila, a great earthquake occurred in 1706. In the region of Rieti, on the same fissure-fault alignment 40 km. west of Aquila, the most recent destructive earthquake took place in 1898; the great catastrophic earthquake of Avezzano near Lake Fucino, 40 km. south of Aquila, occurred in 1915. The seismic centre thus extends from Aquila to 40 to 50 km. radius. It is not volcanic.

height of nearly 3,000 m. in close proximity to the Adriatic sea. Whether it be viewed with its abruptly soaring flanks from either versant, notably from Aquila or Teramo, or as a self-contained, imposing massif from the hills near Rome,<sup>1</sup> it impresses the observer as the great culminating ridge of the Abruzzi, crowned by the towering pyramid of Corno Grande, which can vie with Monte Viso, Monte Grivola, and Matterhorn of the Alps.

<sup>1</sup> The Gran Sasso group is visible, not directly from Rome, but from the hills to the north, about 5 miles from the city, and then only on days of unimpaired atmosphere. In the city itself, the view of the Gran Sasso is intercepted by the imposing massif of Mte. Velino, Mte. Morrone, and Mte. d'Ocre, 2,000 to 2,200 m. in altitude.

## II.

### The Lazio Group (Alban Hills).

- I. THE VOLCANIC GROUPS AROUND ROME.
- II. THEIR AGE AND ORIGIN.
- III. THE LAZIO GROUP.  
SKETCH-MAPS, FIGS. 4 AND 5.

#### I. THE VOLCANIC GROUPS AROUND ROME.

THE volcanic groups to be described in this and the next paper occupy collectively an area of no less than 5,000 sq. km., or 2,000 sq. miles, which in Pliocene times was submerged by the Tyrrhenian Sea from the present seaboard 40 km. inland to the foothills of the Apennines. It was during and after the gradual uprise of the land and the consequent retreat of the sea that that area of sedimentary origin was, in early Quaternary times, converted into the enormous volcanic region comprising the Lazio or Albano hills south of Rome, the Roman Campagna in the centre, and the Bracciano, Viterbo, and Bolsena uplands north of Rome. Under Roman dominion the three last-named groups constituted Southern Etruria.

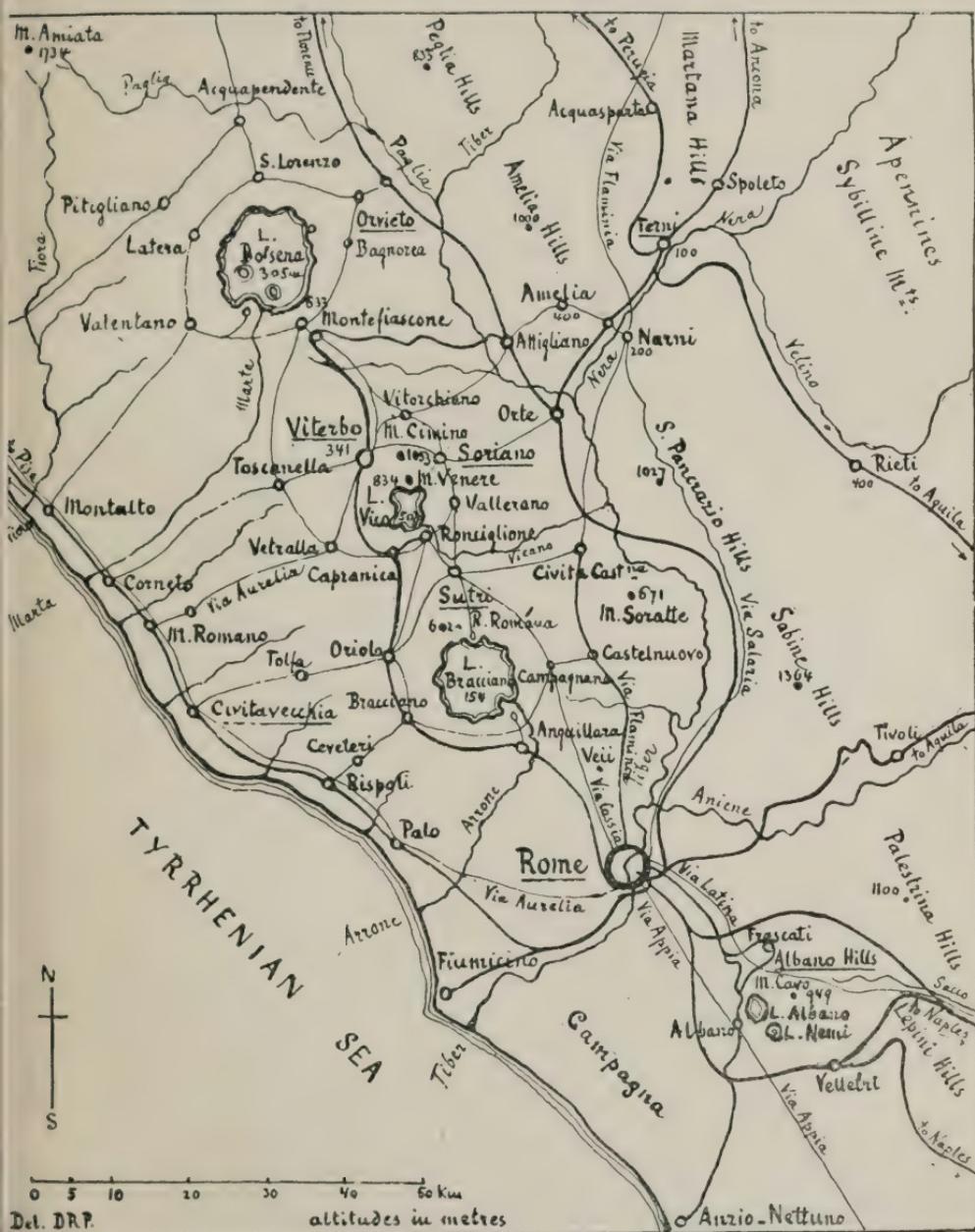
The volcanic area, 120 km. in total length, is bounded on the west by the Tyrrhenian Sea and on the east by the Mesozoic and Tertiary ranges, about 1,000 m. in altitude, of the Peglia, Amelia, S. Pancrazio, and Sabine Hills. Along their eastern base flows the Tiber, which, together with its northern tributary, the Peglia, forms the boundary of the volcanic area from Orvieto to Orte and Rome. From here the area is flanked by the Tertiary hills of Tivoli, Palestrina, and the Lepini range.

The bibliography of the different groups of the volcanic area is very extensive. Suffice it here to mention only a few of the many notable writers of the last fifty years, such as Pilla, Ponzi, Verri, and Moderni as representing the now obsolete theory of the wholly submarine formation and later upheaval *en masse* of the volcanoes; Stoppani and De Stefani as sustaining, on geological grounds, the opposite, rational view in favour of subaerial formation; the mineralogical, petrographic, chemical, and other partial geological contributions of v. Rath, Brocchi, Bucca, Tittoni, Deecke, Mercalli, Klein, Ricciardi, Aichino, and Washington, more especially on the lavas of S. Etruria; and, as the most recent works, V. Sabatini's Memoirs on the Lazio and Viterbo (Cimini) groups respectively.<sup>1</sup> Of special interest and importance are also Clerici's extensive

<sup>1</sup> P. Moderni, "Bolsena": Boll. R. Com. Geol. It., 1903-4. Sabatini (Bracciano), *ibid.*, 1896. H. S. Washington, "Italian Petrological Sketches": Journ. Geology, Chicago, 1896-7. The Roman Comagmatic Region, 1906. V. Sabatini, "Vulcano Laziale": Mem. R. Com. Geol. It., 1900. "Vulcani Cimini": *ibid.*, 1912. The works of the other authors may be gleaned from the bibliographical lists in Sabatini's Memoirs.

The Volcanic Groups around Rome (Lazio and S. Etruria).

Fig. 4.



investigations of the diatomaceous deposits intercalated between the eruptive products, notably in the Roman area, showing that the volcanoes were built up predominantly in brackish and fresh water expanses on already emerged land, and that submarine eruptions took place only in the initial stage of volcanic activity.

## II. AGE AND ORIGIN OF THE VOLCANIC GROUPS.

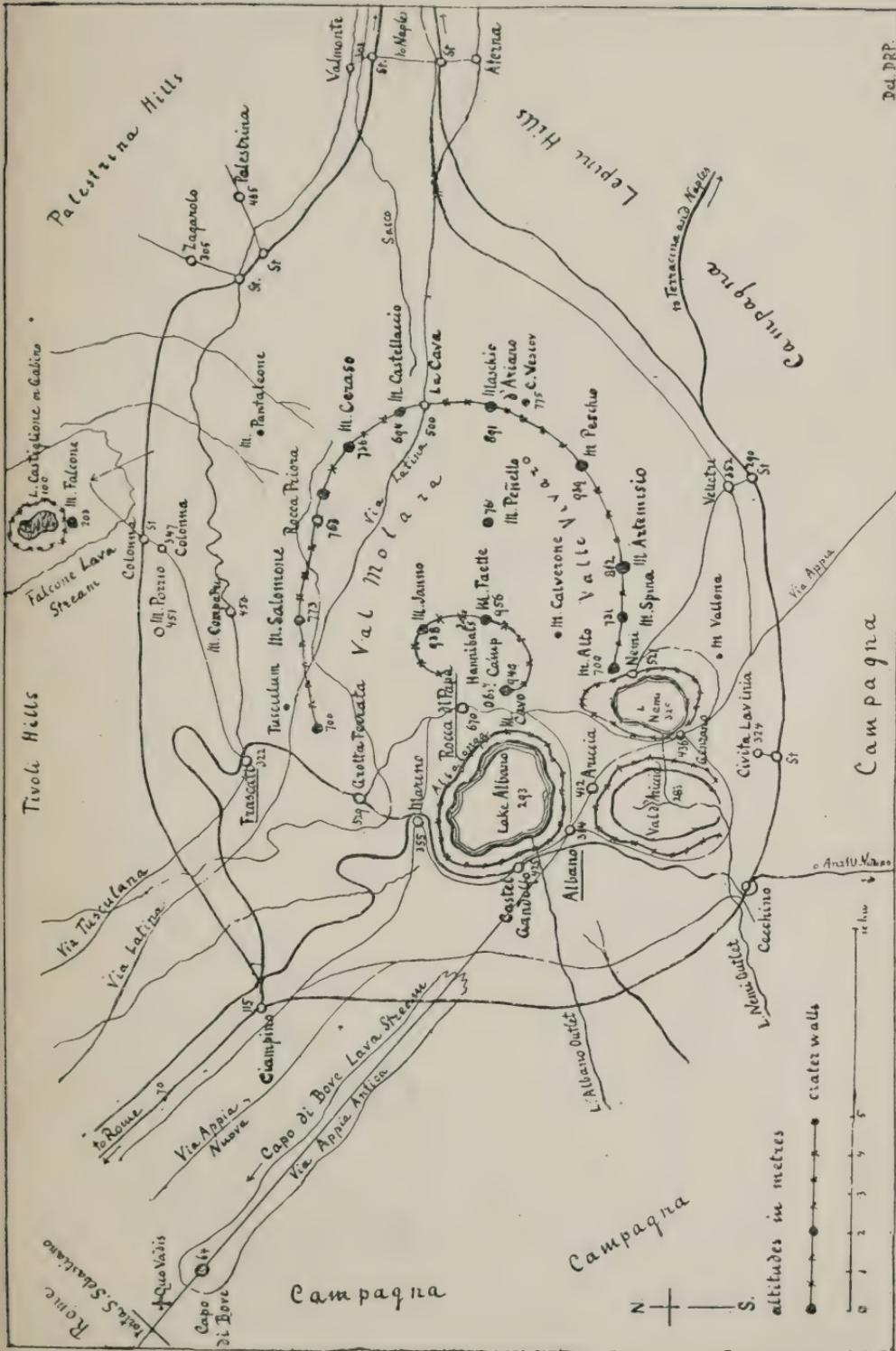
The formation of the volcanic groups south and north of Rome took place contemporaneously and under substantially similar conditions on a great fissure aligned north-west to south-east, roughly parallel to the Tyrrhenian Sea. Towards the end of the Pliocene period the land began to emerge from the sea-belt amid vast marine and estuarine expanses, from which gradually arose the Etruscan and Roman littoral. It was during that transition period of uprise of the land, accompanied by a fall of temperature from the Pliocene tropical to the Pleistocene subglacial, that volcanic activity first manifested itself by sporadic submarine eruptions in shallow expanses, as evidenced by fossiliferous deposits notably on the coast and in the Roman Campagna. With the further uprise of the land the eruptions became subaerial; they gained in frequency, extent, and intensity, and their products helped to reclaim the land from the retreating sea. By this process the emerged sedimentary, mainly Eocene and Pliocene formations were gradually and entirely covered by volcanic deposits to a depth of 100 to 800 m., and the central volcanoes of the three groups reached elevations probably higher than the present ones of 1,000 m. above sea-level.

Among the products of these Quaternary eruptions, those due to explosive activity, i.e. scoria, sand, ashes, lapilli, bombs, blocks and stone fragments cemented to compact or to earthy, incoherent tuffs, are far the largest both in volume and area by direct aerial distribution as well as by secondary mud-flows, retransport, and erosion. On the other hand, effusive products, i.e. lava flows, though individually sometimes of enormous magnitude, represent collectively a very small percentage, the proportion of lavas to tuffs varying from 1 : 200 to 1 : 600. The older compact tuffs and lavas, the peperino or breccia varieties, pozzolana earth either as such or as disintegrated lava or tuff, and, lastly, travertin as a mixed sedimentary and volcanic by-product, have from the earliest times been the staple building materials of Latium, Rome, and S. Etruria.

Owing mainly to the enormous quantities of incoherent tuff, i.e. loosely cemented volcanic ash, which covers large areas in all the four groups, the flanks and marginal slopes of the volcanoes are throughout furrowed by deeply eroded ravines, and the disintegration and denudation of the surface soil have been, and still are, potent factors in gradually changing and attenuating the configuration of the entire region.

### *The Lazio Group (Alban Hills).*

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## III. THE LAZIO (ALBAN HILLS) GROUP.

1. General Features.
2. The Volcanic Edifice.
3. The Products of Eruption.
4. Petrographic Note and Tables.  
Map, Fig. 5.

1. *General Features.*

The Albano Hills, a familiar object as seen from Rome, rise from the Campagna at a distance of 12 km. from the south-eastern gates of the city to a maximum altitude of 1,000 m., and, within the girdle of railways which encircles their base 20 km. in diameter, cover a roughly circular area of about 400 sq. km. The well-cultivated lower and middle slopes and depressions, with their vineyards and olive plantations, the picturesque summer resorts, the shady chestnut and pine woods up to the very summit, the lakes and the copious springs of excellent water, the salubrious air free from miasma, and the magnificent prospect of land and sea all around—all these offer a strange and exhilarating contrast to the dead monotony of the Campagna which separates the Lazio from Rome. The fascination which that group of hills has exercised from the earliest times is attested by the numerous towns, most of them of great antiquity, which adorn the flanks and form a complete chain within the cultivated zone of 300 to 500 m. altitude. A special position is occupied by the steeply terraced town of Rocca di Papa, 670 m. in altitude, at the foot of the historic Mte. Cavo (949 m.), in ancient times crowned by the temple of Jupiter of Latium.

2. *The Volcanic Edifice.*

The central volcano of the Albano group is composed of two, though not concentric, cones, of which the outer and original one, 939 m. in greatest altitude, is the Tuscanian, also called the Artemisian cone, and the inner and later one, 956 m. in maximum elevation, the Lazio cone. The depression or corridor between the two is known as Val Molara, through which runs the Via Latina. The rim of the outer, truncated cone measures 10 km. in diameter, while the volcano embracing the entire group is double that diameter at its base, or 60 km. in circumference. It is built up on an Eocene,<sup>1</sup> Pliocene, and Quaternary sedimentary foundation which rises to 200 m. above sea-level, so that the actual height of the superposed volcanic structure is no less than 800 m. The peaks or teeth of the

<sup>1</sup> Throughout the Roman lowlands and uplands Miocene deposits are extremely rare, the Eocene being in most cases directly overlain by Pliocene deposits.

outer rim, on the whole well preserved, vary in altitude from 700 to 900 m., the highest being Mte. Peschio on the south-east (939 m.). The outer, originally circular crater was by a later explosion partially demolished, breached, and converted into the form of a horseshoe open on the west. The same explosion produced the inner cone, whose rim is 2 km. in diameter and attains its highest points in Mte. Cavo (949 m.) and Mte. Faette (956 m.), the height of the cone from the crater base being 500 m. Its roughly elliptic crater, popularly called Hannibal's Camp, is open at its demolished and eroded western end; it thus presents, like that of the outer one, the form of a horseshoe.<sup>1</sup>

A still later period of volcanic activity, due to the thrice repeated shifting of the eruptive axis, was signalized by the successive formation of three truncated cones on the western and south-western flanks of the principal volcano, i.e. those of Nemi, Albano, and Ariccia, of which the two first became the present crater lakes and the last an extinct lake basin. The well-defined basin of Lake Nemi, with steep crater walls, 325 m. in altitude, 3 km. in greatest width, and 34 m. deep, is composed of two intersecting craters, and is therefore elliptic in outline. The same applies to the crater of Lake Albano—a few kilometres north-east of Lake Nemi—293 m. in altitude, 4 km. in greatest width, and no less than 170 m. in depth, and also to the third crater, i.e. that of Val d'Ariccia, south of Lake Albano, at 283 m. altitude and 3 km. in greatest width. This last-named basin, formerly also a lake, was filled in its upper part with detritic material and then gradually emptied itself by an exit at its southern end.<sup>2</sup>

The explosive formation of these three minor cones helped, each in its turn, to demolish part of the principal or Tuscan cone, whose south-western flanks are therefore greatly broken up into furrows and cut by torrential erosion. Both Lake Albano and Lake Nemi are drained by artificial subterranean exits of great antiquity,<sup>3</sup> that of the latter lake passing into and joining the outlet of the basin of Val d'Ariccia. Besides the five most conspicuous and successively formed cones the Lazio group exhibits a considerable number of parasitic cones scattered all over the area and raised on secondary

<sup>1</sup> The northern part of the inner crater-rib is surmounted by the separate, later, secondary cone of Mte. Janno (936 m.).

<sup>2</sup> North of the Albano Hills, near Mte. Falcone, towards Tivoli, lies the volcanic lake basin of Castiglione or Gabino, at 100 m. altitude, now dried up. The crater is about 1 km. in width.

<sup>3</sup> Livy records that in 354 Roman era (396 B.C.), the year of the destruction, after twenty years' siege, of the Etruscan stronghold Veii north of Rome, Lake Albano overflowed and caused great devastation. The subterranean exit, which is still in operation, was constructed in the following year, 395 B.C. The similar exit of Lake Nemi and the lake itself are also of great antiquity, for the latter existed already when the Romans brought the statue of Diana from Tauris and erected it on the cliff, i.e. on the crater-rib, overlooking the lake since then called "Diana's Mirror".

eruptive fractures which radiate from the central volcano. Many of these smaller cones are densely wooded, and were probably formed during the declining and spasmodic volcanic activity of the group. Others again are, as usual, the favourite sites of ancient towns and strongholds perched on the very summits, such as Civita Lavinia, Velletri, Commatri, Mte. Porzio, and Colonna on the southern, eastern, and northern flanks of the central volcano.

### *3. The Products of Eruption.*

The distribution of the volcanic products of the Albano group over the whole area of 1,400 sq. km. within a radius of 20 km. from the Tiber to the Lepini Hills<sup>1</sup> and from the Tyrrhenian coast to the hills of Tivoli and Palestrina may be summarized as follows :—

(1) The inner area of 400 sq. km. within the circular base of the volcanic group proper, equal to about one-fourth of the total area, is superficially covered by yellowish, in part peperino, i.e. peppercorn, breccia as the more recent and therefore not very compact products.

(2) The outer area of 1,000 sq. km., comprising Rome and the Campagna, is covered by the yellowish grey tuffs of older eruptions, with large outcropping masses of yellowish compact tuffs which constitute the lowest and oldest members of the volcanic series.

(3) Intercalated between and in part overlying that series of ejected products are the effusive lava flows, the smaller of which are confined to the flanks of the inner area, while the individually largest lie in the outer area. These latter are the flows of Colonna and Mte. Falcone in the northern part towards Tivoli, and the famous Capo di Bove flow, which runs straight across the Campagna south-east to north-west to within three kilometres of the south-eastern gates of Rome. This lava flow, probably derived from a fissure in the Tuscan cone during an eruption of great violence, was originally 15 km., and is now, owing to partial erosion, 10 km. in length. Its width of half a kilometre expands to 2 km. at its terminal near the celebrated Capo di Bove tomb of Cæcilia Metella. Its mean depth is 6 m., so that it represents a total volume of 45 million cubic metres. Its superficial area of 75 million sq. m. is considerably in excess of the largest recorded lava flows of Vesuvius, but is exceeded by those of Etna.

<sup>1</sup> About 30 km. south-east of the Albano group, but independent of the same, lies the small volcanic area of the Ernici Hills, on the left of the Sacco Valley above Ferentino and Frosinone, opposite the Lepini Hills. The lava is almost wholly leucite-tephrite.

The proportion of lavas to tuffs, i.e. of effusive to explosively ejected material, of the Albano group has been computed at 1 : 600, and the aggregate volume of all the volcanic products of the whole area of 1,400 sq. km. and a mean depth of 143 m., at 200 cubic km., equal to 50 cubic miles.<sup>1</sup>

The volcanic activity of the group greatly declined towards the end of the Quaternary period, and its last eruptive manifestations, recorded by Livy<sup>2</sup> as having taken place between 640 and 214 B.C., were restricted to the ejection of stones and bombs accompanied by violent atmospheric phenomena. The present remains of that activity are confined to hot springs, gaseous emanations, and not infrequent seismic disturbances, to record and investigate which a geodynamic observatory has been installed at Rocca di Papa, below Mte. Cavo.

#### 4. PETROGRAPHIC NOTE.

I. *Lavas*.—(1) *Leucitites*.—The lava flows of Lazio are almost entirely composed of compact grey to greenish leucitites, in some cases exclusively of leucite and augite, in others with associated olivine, biotite, nepheline, melilitite, and abundantly disseminated magnetite grains.<sup>3</sup> Some of the lavas are wholly micro-crystalline, others with porphyritic phenos<sup>4</sup> of those elements. The green augite is often altered to a yellow nucleus or rim. Leucite of first consolidation appears in large and small phenos; that of second consolidation as segregations in the matrix. Olivine is relatively scarce; it occurs more especially in the lavas of Mte. Cavo and Lake Nemi. Biotite is frequent as element of second consolidation; nepheline even more so. The famous Capo di Bove lava is so densely packed with yellow, honey-coloured, sometimes olive-green specks of melilitite that it constitutes a melilitite-leucitite also containing nepheline. Similar lava also occurs on Rocca di Papa and in several other localities of the group. SiO<sub>2</sub> of normal leucitite 45 per cent.

<sup>1</sup> V. Sabatini, *Vulcano Lazale*, p. 137.

<sup>2</sup> Livy records an eruption of stones and bombs in 115 Roman era (640 B.C.) at Albalonga, proceeding from Mte. Lazio amid lightning and tempest and Jupiter's voice of thunder from the mountain, summoning the Albans to sacrifice. A similar eruption is recorded in 540 Roman era (214 B.C.). The other records are not reliable, as they obviously refer only to abnormal storms and floods.

<sup>3</sup> Leucitic lava contains from 6 to 10 per cent. mean 8 per cent K<sub>2</sub>O, and on this ground the extraction of potash from the Roman and Neapolitan lavas (Lazio, S. Etruria, Roccamonfina, and Vesuvius) has been proposed by P. Moderni (*Leucitiche Vulcani Italiani*, 1914), H. S. Washington (*Italian Leucitic Lavas*, 1918), and others. The computed aggregate of over 100,000 million tons of those lavas would yield 8,000 million tons of potash for fertilizing and industrial purposes, i.e. 1 ton lava = 80 kilos potash. The commercial feasibility of such a scheme, unless undertaken on a very large scale, is, however, open to doubt.

<sup>4</sup> Phenos = abbreviation of phenocrystals.

(2) *Altered Leucitites : Sperone.*—This much-debated product of alteration of leucite lines the rims of the summit (Mte. Cavo) and the other principal craters and extends to the upper, but not to the lower, slopes of the cones; in the Capo di Bove (Campagna) lava it is conspicuously absent. It is honey-yellow or reddish in colour, this being due to chloritic emanations from the craters during eruption, which altered the scoriaceous sheath of the normally dark-grey lava. This process proceeds from the nucleus to outside, the original grey changing to green and then yellow. Sperone lava is the more porous and scoriaceous the nearer it occurs to the vents or centres of eruption ; it is notably so in the vicinity of fumaroles. The lava thus altered exhibits more augite both as microliths and phenos, but less biotite and magnetite, an associated mineral being garnet, which accounts for the higher silica percentage of 46 per cent. In some lava flows leucite appears in second consolidation altered to sanidine, labradorite, anorthite, albite, also to nepheline, always massed together or associated with the other minerals of the same consolidation.  $\text{SiO}_2$  45 per cent.

(3) *Leucite-Tephrites.*—This lava occurs mainly in erratic blocks near Tavolato and Capannelle station in the Campagna, and in situ only on the slope between Lake Nemi and the town of Nemi above. Plagioclase is abundant in both first and second consolidation, together with large leucite phenos up to 2 cm. in diameter, augite, subordinate biotite, magnetite, and nepheline, with associated large blue and white hauyne crystals, as also melanite. On Lake Nemi a bank of tephritic lava is intercalated between banks of leucite. As a rule, Lazio lavas with large felspar phenos as altered leucite are always tephrites, i.e. products of alteration of leucitite.  $\text{SiO}_2$  of erratic blocks 51 per cent, of Lake Nemi tephrite 48 per cent.

II. *Peperino Tuffs.*—Apart from the ordinary compact and loose yellow leucitic tuffs of ashes, lapilli, and scoria, a special type is the peperino tuff, which is developed more especially on the slopes of Lake Albano as *lapis albanus*, and as *lapis gabinus* around the dried-up Lake of Gabino or Castiglione crater, an outlier on the northern periphery of the Lazio group. Peperino, which has from remote times been extensively quarried for building and paving purposes in Rome, is a breccia or massive paste of volcanic ashes and lapilli with countless enclosures of minerals and sedimentary rock fragments often so densely packed that the ashy cement almost disappears. In the ashy paste are abundantly disseminated well-formed, remarkably fresh mineral crystals of great variety, with other enclosures<sup>1</sup> of mineral aggregations, lava fragments, and angular fragments of dolomitic limestone up to 10 cm. in size, conspicuous by their pale yellow colour in contrast to the dark paste in which they are embedded.

<sup>1</sup> Enclosures embedded in the paste or mass, as distinguished from inclusions contained in individual minerals.

The Albano peperino, pale to dark-grey in colour, is particularly rich in those enclosures; the darker Gabino type contains fewer mineral elements, but its paste is richly studded with dark lapilli which sometimes predominate over all the other constituents. The principal mineral enclosures of peperino comprise leucite, augite, biotite, calcite, and zeolites, occasionally also olivine, plagioclase, sodalite, hauyne, garnet, and rarely quartz grains. These minerals, also the limestone enclosures, are often enveloped in a blackish, vitreous, scoriaceous sheath.

Between Albano and Ariccia the peperino banks of the two types often abut against, or promiscuously overlie each other. The Gabino type has often the appearance of indurated mud, i.e. the product of secondary mud-flows, whereas the Albano type, as shown by the angular limestone fragments, is a breccia clearly formed in situ. The further the peperino banks are from the two lakes respectively, the fewer are the enclosures. Hence the inference that the enclosures were ejected and deposited with ashes and lapilli near the rims and on the upper slopes of the crater cones during the eruptions. Near Lake Albano, Castel Gandolfo, Marino, etc., the peperino banks range up to 25 and 100 m., on the peripheral slopes only up to 10 m., in thickness. The banks extend all round the upper slopes of the Lakes of Albano, Nemi, and Valle d'Ariccia in a radius of 4 km., covering an area of over 50 sq. km. On the slopes below the peperino area extend the earthy yellow, leucitic tuffs in a radius of 10 km., and beyond these the compact yellow leucitic tuffs of the Campagna in a radius of additional 10 to 12 km. from the centres of eruption, the last-named tuffs being the older, the other two the more recent explosive, in part re-transported products of eruption. Silica percentage of peperino 45 per cent.

III. *Mineralogical and Chemical Tables.*—The mineralogical and chemical composition of the principal lavas and the peperino tuffs is given in the following tables:—

## MINERALOGICAL COMPOSITION.

*e* = essential.*s* = subordinate.*a* = accessory.

	SiO <sub>2</sub> .	Leucite.	Augite.	Sanidine and Plagioclase.	Olivine.	Biotite.	Magnetite.	Melilito.	Melanite.	Nepheline.	Hauyne.	Garnet.	Sodalite.	Quartz.
icitite and Sperone .	45	<i>e</i>	<i>e</i>	<i>s</i>	<i>s</i>	<i>s</i>	<i>s</i>	—	—	<i>a</i>	—	<i>a</i>	—	—
icitite-Tephrite .	50	<i>e</i>	<i>e</i>	<i>e</i>	<i>s</i>	<i>s</i>	<i>s</i>	—	<i>a</i>	<i>s</i>	<i>s</i>	<i>a</i>	—	—
perino (enclosures) .	44	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	—	—	<i>s</i>	<i>s</i>	<i>a</i>	<i>a</i>	<i>a</i>

## CHEMICAL COMPOSITION.

	<i>Leucitite.<sup>1</sup></i>	<i>Leucite-Tephrite.<sup>2</sup></i>	<i>Peperino.<sup>3</sup></i>
	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub>	45.66	49.90	44.66
Al <sub>2</sub> O <sub>3</sub>	19.65	18.80	15.15
FeO and Fe <sub>2</sub> O <sub>3</sub>	9.25	9.52	22.69
MnO	0.53	—	—
CaO	10.50	4.21	9.94
MgO	2.86	0.80	0.35
K <sub>2</sub> O	6.63	7.51	2.34
Na <sub>2</sub> O	3.79	7.40	0.62
TiO <sub>2</sub>	—	0.07	CO <sub>2</sub> 1.27
P <sub>2</sub> O <sub>5</sub>	0.40	0.23	SO <sub>3</sub> 0.46
Loss by ignition	1.21	0.75	H <sub>2</sub> O 2.36
	100.28	100.28	99.84
Sp. gr.	2.75	2.7	2.5

<sup>1</sup> Aichino (Rocca di Papa), V. Sabatini, op. cit., p. 163.

<sup>2</sup> Aichino (Tavolato and Lake Nemi), op. cit., p. 164.

<sup>3</sup> Aichino (Ariccia), op. cit., p. 66.

### III.

## The Three Groups of S. Etruria.

- I. THE BRACCIANO GROUP.
- II. THE VITERBO GROUP.
- III. THE BOLSENA GROUP.
- IV. CONCLUSION.
- V. PETROGRAPHIC NOTE AND TABLES.  
SKETCH-MAPS, FIGS. 6, 7, AND 8.

AS stated in the introductory part of the preceding paper, the volcanic region north of Rome comprises the three groups of Bracciano, Viterbo, and Bolsena, which together constituted ancient Southern Etruria and now form the northern part of the Province of Rome. Their aggregate area of 3,600 sq. km. or 1,400 sq. miles extends from the lower Tiber northwards to the Rivers Fiora and Paglia, near Acquapendente, as the boundaries of Tuscany, and transversely from the Tyrrhenian Sea to the Tiber as the boundary of Umbria. The three crater lakes so characteristic of the whole region became the centres of the ancient Etruscan communities of the Sabatini, Cimini, and Vulsini respectively, the lakes themselves being named after them. The division of the region into the three groups was thus purely geographical. Geologically it is little more than conventional, for the volcanic products of the three groups overlap each other and even those of the Lazio group were in part projected across the lower Tiber into Sabatinian territory, while those of the Etruscan groups were in part deposited on the boundary hills of Tuscany and Umbria, including the remarkable isolated tuff cliffs on which stand the towns of Orvieto and Orte.

The three groups constitute an uninterrupted area of volcanic uplands, which reach their highest altitude about midway in Mte. Cimino (1,053 m.), near Viterbo, sloping down to about 600 m. both in the Bracciano group on the south and in that of Bolsena on the north. The crater lake of each group forms the centre, which, within a radius of 10 to 20 km., is surrounded by a belt of picturesquely situated small towns perched on volcanic heights, such as constituted a characteristic feature of the region already in Etruscan times. The volcanic cones and craters of the three groups are not as well preserved as those of the Lazio Hills, and the marginal slopes towards the sea on the west and the Tiber Valley on the east from Orvieto to Orte and Rome, are furrowed by deep gullies and crumbling away by disintegration and erosion.

The volcanic phenomena of the Lazio group described in the preceding pages, materially facilitate the interpretation of those of the Etruscan groups, for the volcanic areas of the latter are built up on similar Eocene and Pliocene sedimentary strata ; the process

of their formation extended over the same Quaternary period, and their volcanic products and their crater lakes exhibit substantially similar characteristics.

### I. THE BRACCIANO OR SABATINI GROUP. Fig. 6.

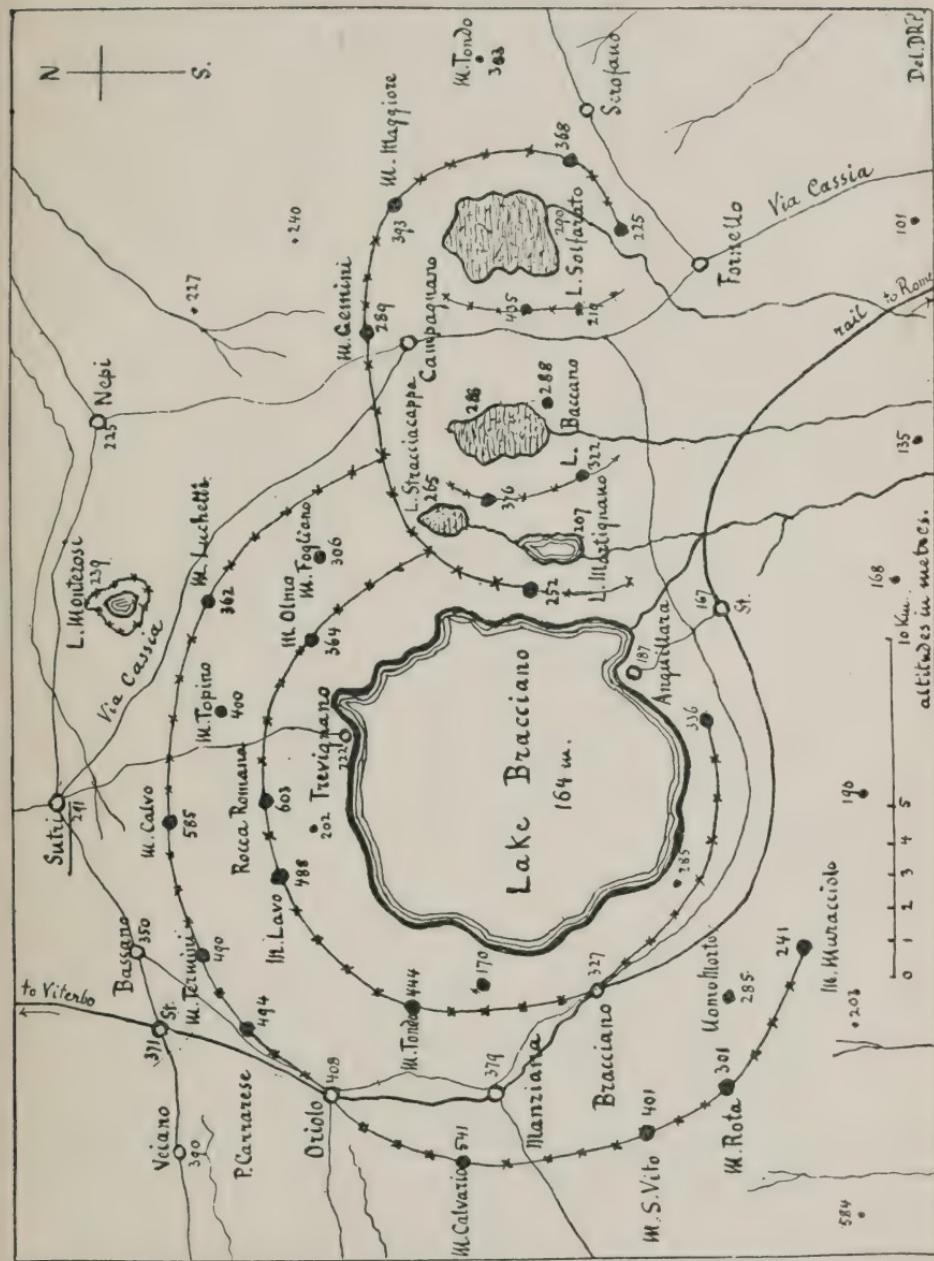
This group, comprising the Sabatinian uplands, 1,300 sq. km. in superficial area, rises gently from the Roman Campagna and its boundary, the lower Tiber, to Lake Bracciano, a large, roughly circular sheet of water, 26 km. in circumference, 8 km. in diameter, and no less than 292 m. in computed greatest depth. Lying at an altitude of 164 m., it is, within a radius of 6 to 8 km., encircled by a double belt of volcanic, mostly tuff hills, which, from 300 m. altitude on the south, near Bracciano, rise to 500 and 600 m. near Oriolo on the west, and culminate, near Trevignano, in Rocca Romana, 602 m., or over 400 m. above the lake. From here they drop again to 300 m., while on the south-east, below the exit of the lake by the River Arrone near Anguillara, the ground falls to 160 and 130 m., whence that river drains into the sea. Immediately east of the lake a separate cluster of lower volcanic hills near Campagnano rises to 200 and 300 m. altitude, including four small lake basins, of which Lake Martignano, nearest to Lake Bracciano, is the only one not yet dried up. These lake basins drain into the exit river of Lake Bracciano, and both, as well as their hill-belts, are open to the south.

According to a now obsolete theory, all the hills and smaller lake basins of the Bracciano group, numbering over fifty, represent an agglomeration of individual volcanic vents or "bocche" of eruption, in the midst of which Lake Bracciano lies as a subsidence trough. It is, however, an established fact that of those hills, largely covered with vegetation, only a few are lava bosses or parts of lava flows, most of them being, not individual cones or craters, but built up of tuff and scoria. The two belts of hills are thus the well-defined remains of one single, double-ringed volcano with a depression or corridor between the two rings, Lake Bracciano being the crater of the inner cone and the main centre of eruption. Similarly the adjacent Campagnano group of four lake basins is a cluster of intersecting craters encompassed by a largely demolished crater wall of greater elevation. The more recent formation of the Campagnano group of elliptic circumference was evidently due to the shifting of the eruptive axis from the central crater whose wall was, by that later explosive eruption, demolished on its eastern side. Both the central volcano and the eccentric volcano of Campagnano are intersecting, and both were, at their southern ends, breached by erosion.

It has, of course, to be borne in mind that the present hill-belts which constitute the evidence of the rings of both volcanoes, are relatively mere ruins of the original ones both in altitude and con-

The Bracciano (Sabatini) Group.

### *The Three Groups of S. Etruria.*



tinuity. The large size, low altitude, and great depth of the central crater lake, whose deepest point or lower end of the crater-funnel lies over 100 m. below sea-level, attest the magnitude of the original volcano. In the course of its eruptions, together with those of the secondary group during the Quaternary period, it projected and distributed its products over an area of 1,300 sq km., or more than three and a half times its own base of 350 sq. km. As in the Lazio group, so also in that of Bracciano, tuffs predominate enormously over lava flows, and thus afford additional evidence of the violence, frequency, and long intermittent duration of the volcanic phenomena. After their abatement and cessation, these phenomena left in historic times down to the present day abundant traces in the form of hot springs and sulphurous emanations.

Between the western part of the Bracciano group and the sea lies the hilly district of Cerveteri and Tolfa (the ancient Tuscia or Tyrrhenia), famous for its Etruscan tombs. The volcanic, craterless hills, built up on Tertiary sedimentary beds, are of Quaternary age, and their lavas, being trachybasaltic, almost all non-leucitic, and acid, are closely related to the similar rocks of the western margin of the Bracciano group, and bear great resemblance to those of Tuscany.

Like some of the latter, the Tolfa lavas were not formed during explosive eruptions of local craters, but as viscous flows from fissures, probably as secondary phenomena correlated with the eruptive centre of Bracciano.

Outside the hill-belt of the lake of Bracciano, about 5 km. north of the Campagnano group, lies another, though small, crater lake, Lake Monterosi (230 m.). The two semicircular bays of Trevignano and Anguillara in Lake Bracciano are steep-walled secondary craters, probably formed during an eruption of the main crater of the lake.<sup>1</sup>

A summary of the predominantly leucitic, in part also non-leucitic lavas and other eruptive products of the Bracciano group is included in the Petrographic Note at the end of this paper.

## II. THE VITERBO OR CIMINI GROUP. Fig. 7.

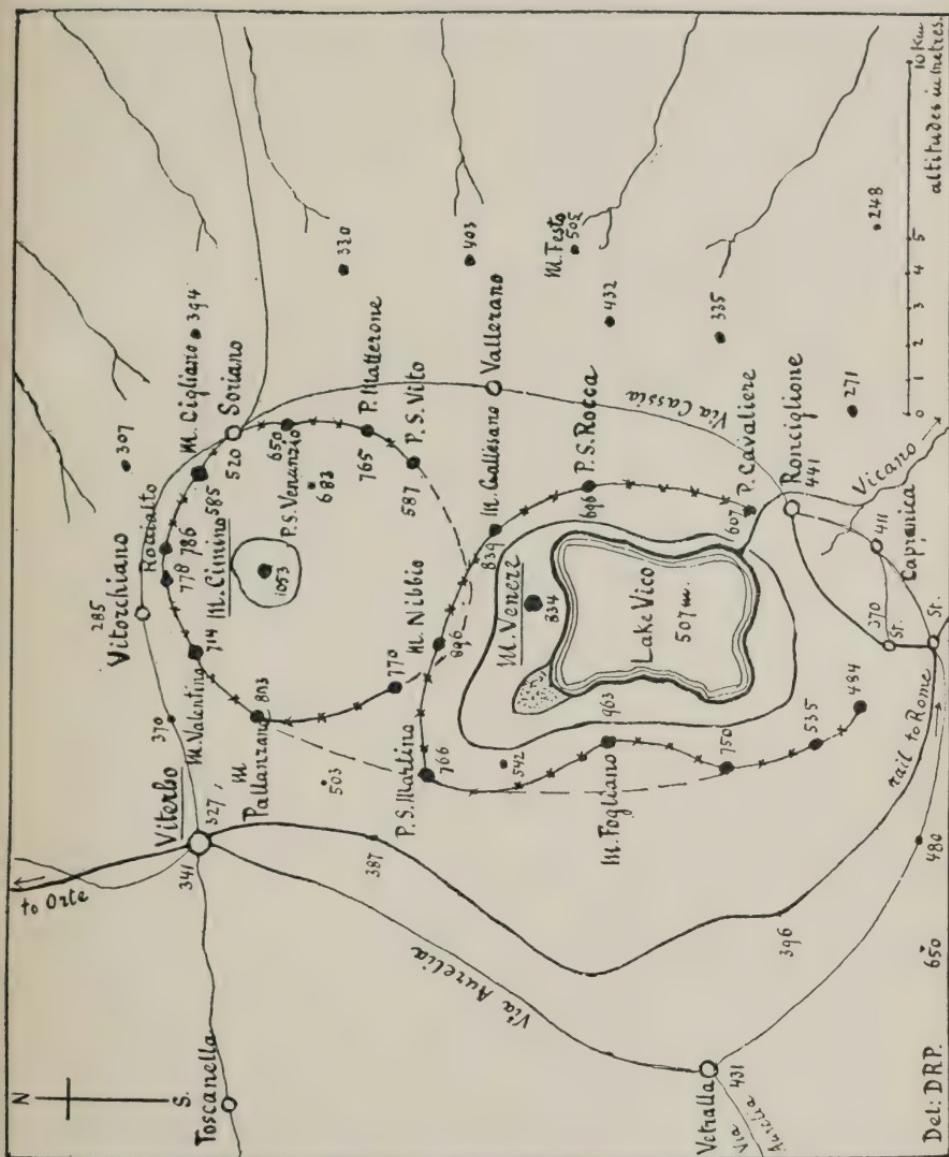
This group is, in its area of 1,000 sq. km., less extensive than the preceding one of Bracciano; on the other hand, its volcanic cones and craters are in certain respects better preserved, and present exceptional, complex, and very instructive features. Its geographical centre is Lake Vico, 10 km. south-east of the ancient city of Viterbo (340 m.), together with which the towns of Vetralla, Capranica, Roneiglione, Bagnaia, and Soriano, and in a wider radius those of Vitorchiano, Sutri, and Civita Castellana form the usual circular chain of the outer lake area. The lake itself exhibits the outline of

<sup>1</sup> East of Lake Bracciano, and overlooking the Tiber Valley, rises the isolated and conspicuous Mesozoic sedimentary ridge of Mte. Soratte (671 m.), the remnant of a range which extended north into Umbria and Tuscany. Mte. Soratte was in ancient times crowned by a temple of Apollo.

The Viterbo (Cimini) Group.

### *The Three Groups of S. Etruria.*

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an irregular rectangle, 18 km. in circumference, 4 km. in greatest width, and 12 sq. km. in superficial area, while its greatest depth is 50 m. and its altitude 507 m., or more than 300 m. higher than Lake Bracciano. On its northern side rises the famous Mte. Venere (834 m.), formerly crowned by a temple of Venus, and 8 km. further north the historic Mte. Cimino (1,053 m.), the geological and volcanic centre of the Viterbo group, and the highest point of the whole region of S. Etruria. In ancient times it was surmounted by the temple of Jupiter of Etruria, which overlooked and protected the great sacred Ciminian forest held by the Etruscans to be impenetrable and impregnable, till the Romans marched through it in 310 b.c.

Mte. Cimino and Lake Vico, the latter with steep crater walls and of sombre aspect, are each, with a radius of 4 to 5 km. encircled by a belt of separate but contiguous volcanic, predominantly tuff and scoria hills, which range in altitude from 500 to 900 m., the highest point of the former belt being Mte. Pallanzana (802 m.), and of the latter Mte. Fogliano (963 m.), over 400 m. higher than the lake. The outer belt or wall of the Mte. Cimino cone is roughly circular, that of Lake Vico and Mte. Venere irregularly elliptic. The position of both cones in relation to their respective outer walls is not concentric but eccentric. The outer walls of the two volcanoes intersect each other, that of Mte. Venere, as the more recent of the two, impinging upon that of its parent. The volcano of Mte. Venere and Lake Vico is breached on the south. The lake has also an artificial exit near Ronciglione, which drains into the River Viciano, an affluent of the Tiber.

The most recent investigations leave no doubt that the base of the original and primary Cimino cone extended considerably further south, and included the area now occupied by Lake Vico and Mte. Venere. That southern part of the great volcano was demolished, first in great part by erosion during a long period of quiescence, and later by a violently explosive eruption which formed the crater of the present lake, while a third period of eruption raised the Mte. Venere cone immediately adjacent to the lake, between the latter and Mte. Cimino.

The chemical and petrographic differentiation of the superposed volcanic products, upon which the sequence of phenomena is founded, shows that after the great initial eruption of Mte. Cimino, followed later by that of the lake and still later by that of Mte. Venere, the two volcanoes experienced throughout Quaternary times further periods of violent eruption both in succession and simultaneously, with long intervening periods of quiescence. The proportion of lava flows to tuffs may be roughly computed at 1 : 200, and the mean thickness of the collective volcanic deposits distributed over the total area of 1,000 sq. km., at 100 m., while in the truncated Mte. Cimino cone itself the volcanic material attains 600 m. in vertical depth.

A special feature of the Mte. Cimino group consists in the mantle of peperino which covers the heights and slopes of the belt of hills or outer ring surrounding the central cone of Mte. Cimino itself. The mantle is composed of two types of peperino: the upper and older type of the heights, and the lower and more recent type of the slopes. Both are in some respects lavic, i.e. effusive in character, but in other respects brecciform, pointing to a peculiar combination of effusive and explosive origin, as will be shown in the Petrographic Note.

The joint elliptic base of the two volcanoes (Cimino and Vico) is 20 by 10 km., or about 200 sq. km., equal to one-fifth of the total area of distribution (1,000 sq. km.) of their products within a radius of 18 km. The point of intersection of the two volcanoes coincides with Mte. Nibbio (896 m.), north of which the corridor between the inner and outer cones of the Cimino group is clearly marked by a depression. Although the basal area is only one-half that of the Bracciano and Lazio groups, the ratio of distribution (1 : 5) of the explosively ejected products exceeds that of those groups (1 : 4). This fact warrants the inference that Mte. Cimino was at one time higher than at present, and is now but the ruin of an imposing volcanic structure, in great part demolished by explosion, erosion, and denudation.

The lavas and tuffs of the Viterbo group are in part non-leucitic, but predominantly leucitic and of considerable variety, as will appear in the Petrographic Note at the end of this paper.

### III. THE BOLSENA OR VULSINI GROUP. Fig. 8.

This group, covering a volcanic area of 1,300 sq. km., equal to that of Bracciano, extends north and north-east to the boundaries of Tuscany and Umbria, i.e. to the valleys of the Fiora, Paglia, and Tiber. Its highest points are Mte. Magno (639 m.) on the western, and Montefiascone (633 m.) on the south-eastern side of Lake Bolsena. On Montefiascone is perched the ancient town of that name, the site of *Fanum Voltumnæ*, the most sacred shrine of the Etruscans. From the Paglia and Tiber Valleys, as well as from the Tyrrhenian coast on the west, the ground rises gradually to the Bolsena uplands of about 600 m. altitude, whence it descends rapidly, in some parts very steeply, to the great basin in which lies the classic lake of Bolsena at an elevation of 305 m., i.e. 300 m. lower than the surrounding hills, and 200 m. lower than Lake Vico.

The lake is at once the largest, the most attractive, and, as regards its origin, the most debated of the three basins of Southern Etruria. Its roughly elliptic outline is 40 km. in circumference, its greatest width 13 km., and its superficial area 112 km. Its two small volcanic islands of Bisentina and Martana (361 and 377 m.) lie near the southern end, whence issues the river Marta, which drains into the sea. Its greatest depth of 140 m. lies between those two islands.

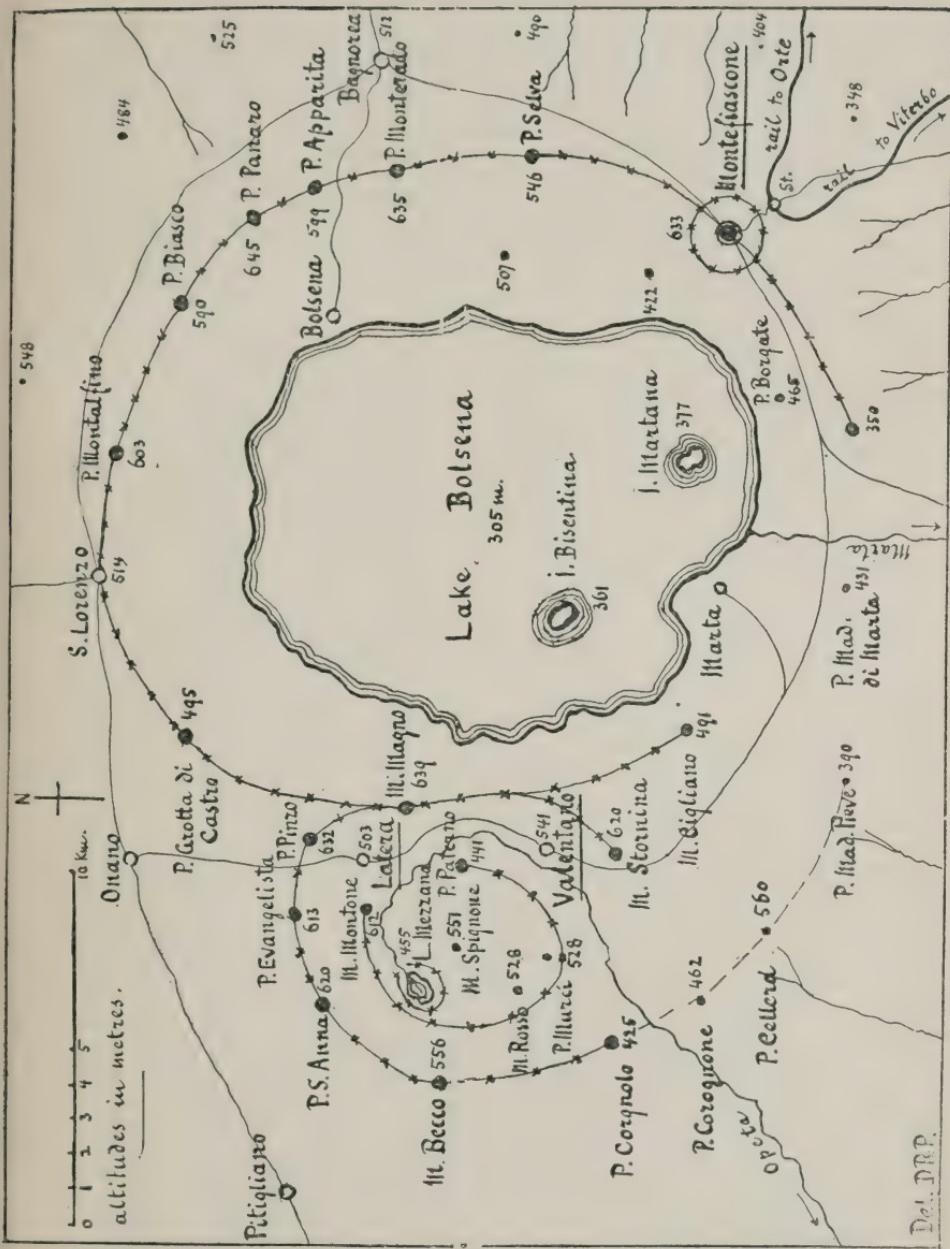
Like the other two lakes, it boasts its circular chain of small towns within a radius of 10 to 20 km., notably Montefiascone, already mentioned, Bolsena, Bagnorea, S. Lorenzo, Pitigliano, Toscanella, Valentano, and Latera, which, like the lake and the fertile country, with its vineyards and chestnut plantations, exhibits a less sombre and, being nearer Tuscany, a more highly cultivated appearance than those of the Viterbo and Bracciano groups.

The key to the interpretation of the volcanic phenomena of the Bolsena group and to the origin of its lake lies, as in the two other groups, in the belt of hills which, within a radius of 10 km., rises from, and encircles the basin. These volcanic, mostly tuff and scoria hills, ranging from 400 to 600 m. in altitude, constitute an incomplete wall, whose roughly elliptic outline strikingly corresponds with that of the lake. In other terms, they represent the remains of the great outer cone of the original central volcano, while the inner cone is evidenced by the steep crater walls, which not only descend into the lake but rise all round from the latter in terraced ledges of foliated tuff, not unlike the scarps and counter-scarps of ramparts.<sup>1</sup> The counter-scarps mark the corridor depressions—partially filled up—between the original outer and inner cone respectively. Within the lake basin the two islands constitute the remains of secondary, intersected cones formed in the crater, whose original vent was probably in the centre at a depth of 130 m., and was later shifted to its present eccentric point of greatest depth of 140 m. The truncated cone of Montefiascone or delle Valli (633 m.) is a secondary cone and crater, 2 km. in diameter, formed on the rim of the central volcano. The same applies to the smaller cone and crater of Monterado (150 m. diameter), 8 km. north of Montefiascone.

The great central volcano, whose basal area equals that of the Lazio group, thus represents at least three distinctly traceable cycles or periods of eruption, in the course of which it underwent repeated partial demolition by explosive action with intermediate quiescent periods of erosion and denudation, until it became reduced to its present attenuated configuration. The lake itself was formed in a closed crater by the copious springs and streams draining into the basin from the crater walls and surrounding hills, and later found its present exit by the river Marta, as already mentioned.

Immediately west of Lake Bolsena rises the second, smaller, but, on the whole, better preserved volcano of Latera or Valentano, composed of two roughly circular, but eccentric cones intersected with the central volcano. The outer Latera cone is represented by a belt of volcanic hills 7 km. in diameter, and from 500 to 700 m. in

<sup>1</sup> These terraced ledges were formerly regarded as contour lines showing the gradual fall of the level of the lake owing to the supposed subsidence of its floor; but the terraces or *scaglioni* are separated by actual depressions, i.e. corridors between successive crater walls, as was first pointed out by Sabatini in 1904 (*Boll. R. Com. Geol. It.*, p. 102).



altitude, the highest being Mte. Magno (639 m.), at the point of intersection, and Poggio Evangelista (663 m.) at the northern end, previously mentioned. The inner cone is formed by a similar belt of somewhat lower hills with eccentric centres; one, the small crater lake of Mezzana (455 m.), while the other adjacent cone is Mte. Montione (612 m.). These two cones, together with Mte. Signano (557 m.) in the actual centre, represent probably immediately successive or simultaneous eruptions. The corridor between the two belts is marked by low depressions. These were formerly lake basins, like Lake Mezzana which they now drain, the common exit being at the southern end, by the small river Opeta. Both the Bolsena and Latera volcanoes were breached on the south, probably by partial explosive demolition, but chiefly by later erosion.

The Latera volcano marks a shifting of the eruptive axis of the central volcano, which, like the Cimino volcano of the Viterbo group, probably extended to the area of the present secondary cones, and was here demolished by the explosive formation of its offspring built up on the ruins of the parent. The base of the latter, 18 km., is two and a half times that of the former. The aggregate area of the two volcanoes proper is 380 sq. km., or about one-third of the total area of distribution of 1,300 sq. km. One of the largest lava flows is that on the western side of the group towards Pitigliano, no less than 11 km. in length and about 2 km. in width. Though apparently proceeding from the northern end of the smaller Latera volcano, its magnitude points to its having flowed from a rent in the great parent volcano before the latter's partial demolition on its original western flank. It is the largest flow in S. Etruria.

Lake Bolsena was until quite recently regarded, not as a crater lake, but as a trough due to a subsidence within the circle of surrounding volcanoes. The evidence now adduced has conclusively demonstrated its volcanic origin as a huge central crater, of which, moreover, abundant examples are to be found on an even larger scale in other volcanic regions, e.g. in Java, Manchuria, Patagonia, Central Africa, etc.

The lavas of the Bolsena group are in part non-leucitic (medium trachybasalts or vulsinites), but predominantly leucitic, varying from leucite-tephrites to leucitite, phonolite, trachyte (petrisco), and basanite, as shown in the Petrographic Note.

#### IV. CONCLUSION.

The outstanding features of the four volcanic groups collectively may, in the present writer's view, be briefly stated as follows:—

1. The four groups are consecutively aligned on a great fissure running north-west to south-east roughly parallel to, and about 20 km. inland from, the present Tyrrhenian Sea, probably along a

fault in the underlying, deep-seated Mesozoic formations. They are built up in the main subaerially on an Eocene and Pliocene sedimentary platform. Their first eruptive manifestations took place in the still partially submerged littoral between the sea and the foothills of the Apennines during the general uprise of the land towards the end of the Pliocene and in the early Quaternary (Pleistocene) period.

2. The area over which the products of eruption, more especially the incoherent tuffs as products of cemented, wind-blown ashes and secondary mud-flows, are distributed in the four groups is more than three times that of the volcanoes proper. The mean thickness of the eruptive products ranges up to 200 m. in the outer areas of distribution, and up to 600 and 800 m. above the sedimentary platform in the volcanoes themselves. The proportion of lavas to tuffs, i.e. of effusive to explosively ejected and retransported material, varies from 1 : 200 to 1 : 600, average 1 : 400.

3. Each group exhibits the characteristic feature of a great central crater varying from 4 to 12 km. in diameter, partially demolished by the explosive formation of a later eccentric crater within, or contiguous to the central one. This centralization of volcanic activity in each group is confirmed by the lava flows being disposed radially around the centres of eruption. All the lakes in the volcanic areas, whether actual or extinct, lie in true crater basins. The dimensions of these, as well as of the volcanic areas, are summarized in the table below.

4. The eruptive activity of each of the four groups with intermediate quiescences falls into three periods: (1) the formation of the central cone and crater; (2) its partial demolition by the explosive formation of a second eccentric cone and crater; and (3) the formation of secondary cones or vents on the rims or on the flanks and fissures of the central or eccentric cones. The eruptions of the four groups began, rose, and fell in intensity during the Quaternary period. The Lazio group, individually the largest, was the last to become extinct, its final manifestations having taken place in historic times.

5. As shown in the Petrographic Note and in the table at foot, the lavas of the four groups are all predominantly, in the Lazio group exclusively, leucitic (hence rich in potash). Non-leucitic, more acid lavas occur only in the groups of S. Etruria. The remarkable uniformity of the leucitic lavas throughout the four groups tends to confirm the close correlation of the latter in respect of their alignment on a common fissure and of their eruptive products being derived from a common magmatic reservoir. The earliest eruptive products of that magma were the leucitic lavas, i.e. in the order of leucitites, tephrites, and their more acid modifications; the eruptive series was closed by the non-leucitic still more acid trachybasalts of S. Etruria, the gradual change of the magma being therefore one of progressive acidity.

TABLE I.—LAVAS OF LAZIO AND S. ETRURIA GROUPS.

Volcanic Groups.	Non-leucitic Lavas.			Leucitic Lavas.			
	Ciminites.	Vulsinites.	Toscanites.	Leucitites.	Tephrites.	Phonolites.	Trachytes (Petrisco).
Lazio . . .			s	p	s	s	s
Bracciano (with Tolfa)				p	s	s	
Viterbo . . .	p	s	p	s	p	s	s
Bolsena : : :	s	p		s	p	s	s

p = predominant      } in respect of non-leucitic lavas.  
 s = subordinate      } in respect of leucitic lavas.

TABLE II.—AREAS OF ERUPTIVE PRODUCTS. DIMENSIONS OF CENTRAL CRATERS AND CRATER LAKES.

	Areas of Eruptive Products.		Central Craters.	Crater Lakes.			Highest points of central crater or cone rim.
	Inner.	Inner. and outer.		Diameter	Area.	Depth.	
Lazio . . .	sq. km.	sq. km.	km.	sq. km.	m.	m.	m.
	400	1,400	10 {	Albano 10	170	293	956 Mte. Faette.
Bracciano . . .	350	1,300	Nemi 5	57	34	325	602 Rocca Romana.
Viterbo . . .	200	1,000	4	12	292	164	1,053 Mte. Cimino.
Bolsena . . .	380	1,300	12	116	50	507	639 Mte. Magno.
					140	305	

## V. PETROGRAPHIC NOTE ON THE LAVAS AND TUFFS OF S. ETRURIA.

The lavas and tuffs of the three divisions of Bracciano, Viterbo, and Bolsena reveal so much uniformity both in origin and composition that for petrographic purposes they may be considered collectively. The two leading types of lava with their corresponding tuffs are the non-leucitic, i.e. trachybasalts as the later eruptive products, and the leucitic, i.e. leucitites and leucite-tephrites as the products of earlier eruptions.

I. *Non-leucitic Lava*s (Trachybasalts). — Washington has classified these lavas as "trachydolerites" in the order of their silica percentage, as Ciminites, Vulsinites, and Toscanites, varying respectively from 50 to 55, 55 to 65, and 65 to 75 per cent, the last of these corresponding to the typical, often quartz-bearing lavas of the Tuscan volcanoes, which in S. Etruria occur only in the Bracciano and the contiguous Tolfa district. Sabatini, on the other hand, has designated them according to their respective dominant felspars as oligoclasites, trachioligoclasites, and trachytes, with subdivisions of the intermediate passages. As the silica percentage offers, on the whole, a more direct and definite criterion, the rational classification should, in the present writer's opinion, be simply basic, medium, and acid trachybasalts, without complicating the nomenclature either by regional or by minute mineralogical distinctions.

(1) *Basic Trachybasalts* (Ciminites).—These lavas occur, in the main, only in the Viterbo division, and are marked by their dark to pale grey holocrystalline groundmass of microplagioclase, augite, and magnetite with sparse vitreous base, and by porphyritically disseminated phenos (first consolidation) of oligoclase, sanidine, augite, and olivine as essential, and magnetite and apatite as accessory elements. Typical lavas are those from near the summit of Mte. Cimino down to Prato della Quercia, midway between Viterbo and Bagnaia; also on the north flank of Mte. Cigliano and immediately west of Soriano.  $\text{SiO}_2$  54 per cent.

(2) *Medium Trachybasalts* (Vulsinites).—Pale-grey to violet, mainly holocrystalline groundmass, with little vitreous base; phenos of sanidine, oligoclase, augite, hypersthene, biotite, and magnetite. Typical vulsinite is that on Via Aurelia, about midway between Viterbo and Vetralla; hence by Sabatini labelled vetrallite. It occurs also between Caprarolla and Ronciglione and round the crater rim of Lake Vico as dark grey scoriaceous lava with pipernoid (streaky, fluidal) structure.  $\text{SiO}_2$  58 per cent.

A variety of vulsinite is Sabatini's oligolabradorite, which contains labradorite besides oligoclase, and is, moreover, marked by the presence of abundant microliths of biotite. The other elements of first and second consolidation are augite, hypersthene, abundant grains of olivine, and accessory apatite. This variety occurs notably near the summit of Mte. Cimino and in several outcrops on the east flank towards Soriano.

Besides these oligoclasite lavas as flows *in situ*, occur both on Mte. Cimino and around the Vico volcano large ejected blocks of phonolite or phonolitic tephrite embedded in the yellow and whitish tuffs. The lava of these blocks is pale grey, and contains—besides lamellar, lucent oligoclase, and sanidine—augite, titanite, magnetite, and minute grains of black and blue hauyne. The origin of this lava is uncertain; it is obviously older than the other lavas, and the

blocks were probably torn from buried lava flows and ejected during later explosive eruptions.

In the Bolsena (Vulsini) division the medium trachybasalts or vulsinites, occur typically on the banks of the lake north of Bolsena, also at Torre Alfino, S. Lorenzo, Mte. Magno, and on Mte. Rado near Bagnora, respectively north, west, and east of the lake.

(3) *Acid Trachybasalts* (Toscanites).—This lava is absent in the Cimini and Bolsena districts, but occurs in the western part of the Bracciano division, and notably in the contiguous and closely correlated district of the Cerveteri, Tolfa, and Mte. del Sasso hills between Bracciano and the sea. The holocrystalline, often also largely vitreous groundmass is composed of micro-plagioclase, biotite, augite, and diopside or hypersthene. The lava is highly porphyritic with phenos of those minerals of first consolidation, olivine and secondary quartz also being occasionally present. The felspar phenos are basic plagioclase, notably labradorite or anorthite. In the Bracciano division it occurs on Mte. Calvario and Mte. S. Vito, west of the lake, and constitutes nearly all the lavas of the adjoining hill groups of Cerveteri and Tolfa. The lava is augite-, biotite-, or quartz-trachybasalt, according as either of these elements is dominant.  $\text{SiO}_2$ , 62 to 67 per cent.

II. *Leucitic Lavas*.—*Leucite-ephrites* are largely represented in all the three divisions, more especially in the area of the Vico crater lake of the Cimini (Viterbo) division. The acid variety, passing to phonolite, is reddish or dark grey in colour, and, besides leucite of first and second consolidation, contains abundant dark-green augite, biotite, olivine grains, plagioclase and sanidine, and accessory magnetite and apatite. In some cases the lava is rich, in others poor in biotite, while again in others that mineral appears not as phenos but only in the groundmass as of second consolidation. A notable, more acid variety is the so-called petrisco (Washington's leucite-trachyte), a pale grey lava with numerous phenos of vitreous, yellowish felspar (sanidine and plagioclase), kaolinized leucite, and some augite. In the groundmass of second consolidation sanidine predominates, oligoclase is subordinate. The more basic variety of leucite-tephrite differs from the acid type mainly in containing more labradorite and augite; its groundmass is packed with micro-leucite and augite. The leading characteristic of the acid variety of the Cimini division is that it contains sanidine and oligoclase only in second consolidation; the basic variety contains in second consolidation only labradorite and anorthite.

The acid variety of leucite-tephrite is typically represented by the lava of Ponte de Quarto, 4 km. south of Viterbo and west of S. Martino. Petrisco occurs on Via Cassia, at Canapine, and on Via Aurelia, south of Viterbo; the basic variety occurs near Vetralla and on Mte. Venere, near Lake Vico.  $\text{SiO}_2$  of the acid and basic

variety 55 per cent and 50 per cent respectively; mean silica percentage of leucite-tephrite 52 per cent.

In the Bolsena division, leucite-tephrites are predominant in the north-eastern and south-western parts, passing to more acid phonolite and petrizzo (leucite-trachyte) notably on the north-western, and to more basic leucite-basanite in the southern part. Typical tephrites occur at S. Trinità near Orvieto and on Mte. Cavallo south of that town; also on Montefiascone, close to the lake; on Poggio Pilate near Valentano and at Mezzano west, and on Mte. Biscuzio and Montalto south-west of the lake. The phonolitic variety occurs east of the lake, north of Bagnoreo. Leucite-basanite (48 per cent silica) occurs near Valentano.

In the Bracciano division leucite-tephrite is less in evidence than leucitite; in a typically basic form (50 per cent silica) it occurs in the crater wall below the town of Bracciano; leucite-phonolite (56 per cent silica) occurs on the north-western bank of the lake.

*Leucitite* is relatively rare in the Viterbo division, and occurs only on the border of the Bolsena division. It is much more frequent in the latter and in the Bracciano division. Like that of the Lazio group, it is a compact dark to pale grey lava, containing—besides predominant leucite and augite—olivine, biotite, nepheline and magnetite both as phenos of first, and in the holocrystalline ground-mass of second, consolidation.

In the Bolsena division leucitites are abundant on the south-east, i.e. near the border of the Viterbo division; they also occur at Sassi Lanciati, on the lake 2 km. south of Bolsena; about  $\frac{1}{2}$  km. north of Bolsena; and, as a nepheline-bearing variety, at Osteria di Biagio, between Orvieto and Bolsena.

In the Bracciano division, where leucitites predominate over tephrites, they occur at Crocicchie south of the lake; on l'Uomo Morto south-west, and at Oriolo north-west of the lake; also in the Cerveteri hills in a ravine close to Mte. Cucco and in the Tolfa hills at the base of Mte. Electo.  $\text{SiO}_2$  48 per cent. Both the leucitites and the tephrites of S. Etruria contain about 3 per cent more silica than those of the Lazio group.

III. *Tuffs*.—The tuffs, spread over the three divisions in enormous quantities, overlap and merge into each other at the geographical boundaries, but they are much alike and correspond in composition with their respective lavas. They range from earthy yellow to white pumiceous, and to leucitic with or without black scoria; the compact tuffs are indistinctly stratified and contain abundant grey and white scoria.

Two special types of tuff are the upper and the lower peperino of the Viterbo division—Sabatini's peperino *delle alture* and *tipico* respectively. The "alture" type crowns the volcanic heights which encircle Mte. Cimino, i.e. Mte. Pallanzana, S. Valentino, Montecchio, S. Vitto and Canepino, Vitorchiano, Cigliano, Mte. Matterone, and Soriano, while the "tipico" forms the superficial deposits of the

lower slopes of those hills, constituting a mantle about 4 km. in width around the greater part of the Mte. Cimino group. This tuff has been extensively quarried for building purposes from the earliest times. The summit of Mte. Cimino itself is covered with ordinary earthy yellow tuff, but the "tipico" is in evidence nearly all around its base up to 600 m. altitude. It varies in thickness from 10 to 80 m. At the points of contact the "tipico" always abuts against or overlies the "alture".

The upper or "alture" peperino is the older of the two; the essential difference between them consists in the condition of their paste and in the enclosures of the same. The "alture" is always much altered, of bleached, dull aspect, the "tipico" fairly to perfectly fresh and unaltered, the mineral crystals are often lucent. This difference also applies to the colour, which, when unaltered, is pale to dark grey, passing to greenish, whitish, reddish, and yellowish. The composition of the "alture" is that of lava mixed with breccia; hence this peperino has well been termed a lavic breccia or brecciated-lava. Washington has applied this term also to the "tipico", but the latter is, as Sabatini has shown conclusively, of detritic origin, i.e. a true breccia, though different from the Lazio peperino, which contains much less silica. The "alture" type exhibits macroscopically all the features of lava, i.e. of an effusive rock similar to vulsinite (trachioligoclase); microscopically it appears now lavic, now detritic. In the present writer's view the "alture" peperino is the product of a simultaneous eruption of lava and ash-showers mixed together, while the "tipico" is the product of ash-showers of a later, purely explosive eruption. The resultant "tipico" tuff probably covered also the heights, which were later denuded down to the older "alture"; hence the exposed patches of the "alture" on the heights and the "tipico" mantle on the slopes.

The dark grey or reddish paste of the "alture" type contains among its numerous enclosures small masses of plagioclase and large crystals of sanidine, augite, hypersthene, and biotite. The pale to dark grey pepper-like "tipico" is packed with countless microliths of plagioclase, together with much less augite, hypersthene, and biotite. Lapilli are often so densely packed in this breccia that they form masses; it also contains pumice-stones and indurated argillaceous fragments. The abundance of angular fragments of all dimensions leaves no doubt as to the "tipico" being a true breccia. The test of the priority of age of the "alture" peperino is that it contains no enclosures of "tipico", whereas the latter frequently contains enclosures of the "alture" type.

A variety of grey, violet to greenish peperino occurs in a quarry near Vetralla, where it is 30 m. in thickness. This variety, schistose and banded under pressure, shows pipernoid (streaky, fluidal) structure like the piperno of the Phlegræan Fields. It contains numerous enclosures of black pumice, and is marked with countless yellow pumiceous specks, which give it a peculiar spotted

appearance. It contains no microliths, no hypersthene, and fewer crystals of felspar, augite, and biotite, a feature which differentiates it from the "tipico" and "alture". Mean  $\text{SiO}_2$  of peperino 63 per cent, of the ordinary yellow tuff 51 per cent.

The following tables show the mineralogical and chemical composition of the principal lavas and of the peperino of S. Etruria, more especially of the Cimini (Viterbo) division :—

TABLE OF MINERALOGICAL COMPOSITION.

*e* = essential.*s* = subordinate.*a* = accessory.

	$\text{SiO}_2$ p.c.	Oligoclase.	Plagioclase.	Sanidine.	Leucite.	Augite.	Olivine.	Biotite.	Nepheline.	Magnetite.	Apatite.	Hausse.	Quartz.
<i>Non-Leucitic Lavas.</i>													
Trachybasalts—													
Basic (Ciminites). . .	54	<i>e</i>	<i>s</i>	<i>s</i>		<i>e</i>	<i>e</i>	—		<i>a</i>	<i>a</i>	<i>s</i>	
Medium (Vulsinates) . .	58	<i>e</i>	<i>e</i>	<i>e</i>	—	<i>e</i>	<i>s</i>	<i>e</i>	—	<i>e</i>	—	<i>s</i>	
Acid (Toscanites) . . .	65	<i>e</i>	<i>e</i>	<i>e</i>	—	<i>e</i>	—	<i>e</i>	—	<i>s</i>	—	<i>s</i>	
Phonolitic Tephrite (ejected blocks)	59	<i>e</i>	<i>e</i>	<i>e</i>	—	<i>e</i>	—	—	—	<i>s</i>	—	<i>a</i>	
<i>Leucitic Lavas.</i>													
Leucite-Tephrite . . .	54	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>s</i>	<i>e</i>	—	<i>s</i>	<i>a</i>	—	
Petrisco (Leucite- Trachyte)	56	<i>s</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>s</i>	—	—	—	<i>s</i>	—	—	
Leucitite . . . .	45	<i>a</i>	<i>a</i>	—	<i>e</i>	<i>e</i>	<i>e</i>	<i>s</i>	<i>s</i>	<i>s</i>	—	—	
I. Peperino (enclosures).	63	<i>e</i>	<i>e</i>	<i>e</i>	—	<i>e</i>	—	<i>e</i>	—	<i>s</i>	<i>s</i>	<i>e</i>	—

TABLE OF CHEMICAL COMPOSITION.

	<i>Trachybasalts.</i>				<i>Ciminite.<sup>1</sup> Vulsinite.<sup>2</sup> Toscanite.<sup>2</sup></i>				<i>Leucite-Peperino.<sup>1</sup> Leucitite.<sup>2</sup> Tephrite.</i>				
	%	%	%	%	%	%	%	%	%	%	%	%	Acid. <sup>1</sup>
$\text{SiO}_2$ . . .	53.82	57.32	65.19	62.85	47.89	54.44	49.73						
$\text{Al}_2\text{O}_3$ . . .	16.19	19.84	16.04	17.97	18.25	16.78	19.20						
$\text{FeO}$ and $\text{Fe}_2\text{O}_3$	7.58	4.56	3.64	5.95	8.57	9.65	7.91						
$\text{MgO}$ . . .	7.02	1.60	0.99	1.24	3.68	2.04	2.63						
$\text{CaO}$ . . .	7.28	3.82	2.92	3.79	8.70	5.63	7.96						
$\text{Na}_2\text{O}$ . . .	1.70	3.22	2.26	3.0	2.60	4.77	1.99						
$\text{K}_2\text{O}$ . . .	6.28	9.15	6.11	4.69	8.23	6.40	9.39						
$\text{P}_2\text{O}_5$ . . .	—	—	—	0.18 $\text{TiO}_2$	0.77	—	—						
Loss by ignition	0.10	0.57	1.85	0.10	0.65	—	1.19						
	99.95	100.09	99.00	99.77	99.34	99.78	100.00						
Sp. gr. . .	2.78	2.61	2.5	2.5	2.78	2.6	2.65						

<sup>1</sup> Aichino, Sabatini, op. cit.<sup>2</sup> Ricciardi and Washington, op. cit. The above analyses represent the mean composition, derived from Aichino's, Ricciardi's, and Washington's analyses of lavas from several localities in S. Etruria referred to in the present Note.

## IV.

### The Roccamontina Group.

- I. INTRODUCTORY.
- II. GENERAL FEATURES.
- III. THE VOLCANIC EDIFICE.
- IV. THE PRODUCTS AND PERIODS OF ERUPTION.
- V. THE LATERAL CONES AND LAVA FLOWS.
- VI. CONCLUSION.
- VII. PETROGRAPHIC NOTE AND TABLES.  
SKETCH-MAP, FIG. 9.

#### I. INTRODUCTORY.

THE volcanic group of Roccamontina, 50 km. north of Naples, gained considerable prominence, and even renown, in the earlier days of vulcanology, when L. von Buch, Elie de Beaumont, Abich, Pilla, and others propounded the theory that volcanoes are igneous masses thrust up by the pressure of the molten nucleus of the earth against the earth's crust. In 1841 Abich<sup>1</sup> pronounced Roccamontina the finest example of an "upheaved volcano" not only in Italy, but in Europe, and Pilla,<sup>2</sup> in his writings of the same period, fervently embraced and sustained the same view. Considerably later, when that theory had become obsolete, Vom Rath<sup>3</sup> published, in 1873, a Note on two of the typical rocks of the group. This was followed in 1886 by L. Bucca's petrographic Note on the principal lavas,<sup>4</sup> and in 1889 by P. Moderni's contribution of his geological investigations<sup>5</sup> which had yielded the copious material for Bucca's work. The latter was supplemented by H. S. Washington's substantially confirmatory petrographic Note of 1897.<sup>6</sup>

#### II. GENERAL FEATURES.

The self-contained, most instructive volcanic group of Roccamontina, rising at a distance of 20 km. inland from the Bay of Gaeta, is reached from the railway station of Mignano, or more easily from that of Teano, both on the Rome and Naples main line, or from Sessa Aurunca, a station on the Tyrrhenian coast railway, 12 km. west of Teano.<sup>7</sup> The former railway skirts the base of the

<sup>1</sup> H. Abich, *Vulkanische Bildungen*, Brunswick, 1841, p. 126.

<sup>2</sup> L. Pilla, *Application de la théorie des cratères de soulèvement au volcan de Roccamontina*, Paris, 1844; also *Mem. Société géol. France*, 1845, p. 326.

<sup>3</sup> G. vom Rath, "Zwei Gesteine der Roccamontina": *Zeitschr. D. geol. Ges.*, 1873, p. 243. W. Deecke, *Führer durch Campanien*.

<sup>4</sup> L. Bucca, "Il Monte di Roccamontina": *Boll. R. Com. Geol.*, 1886, p. 245.

<sup>5</sup> P. Moderni, "Note Geologiche Roccamontina": *Boll. R. Com. Geol.*, 1889, p. 74.

<sup>6</sup> H. S. Washington, *Italian Petrographic Studies*, 1897, p. 241.

<sup>7</sup> In Strabo's time, Teano (Teanum) was, next to Capua, the most flourishing city of the Campania. Sessa, too, was an important city in the days of Horace and Virgil, who met near there.

group on the north and east, the latter on the south; both of them thus afford a fairly close view of the volcano. Mignano lies on the north-eastern, Teano on the eastern, Sessa on the western margin of the group, the first of these being about 12 km., the other two about 10 km. distant from the little town of Roccamonfina, which, at an altitude of 600 m., nestles in the very centre of the original crater, at the foot of the inner cone. The group is more or less surrounded and closed in by the Eocene limestone hills of Presenzano and Mte. Camino on the north and west, of Mte. Massico on the south, and of Mte. Maggiore on the east, the gaps between them being traversed by the River Garigliano and by numerous streams which, in deep-cut ravines, fissures, and gullies, radiate from and collect the drainage of the volcanic hills. The limestone circle ranges from 500 to 1,000, the volcanic group within that circle from 800 to 1,000 m. in altitude, while the depression between them varies from 50 to 150 m. above sea-level, and thus lies about 800 m. below the culminating points of the region. It is this position of the volcanic group in a basin encircled by a Tertiary limestone belt that lent apparent weight to the fallacious theory of the volcano having been upheaved *en masse* through the successive formations of the earth's crust, and of its cupola having burst in the form of an eruption through pressure from below. All recent experience of volcanic phenomena shows the contrary to be the case, i.e. that the reservoirs of molten magma have their seats at relatively inconsiderable depth, perhaps not more than some thousand metres below the surface at sea-level, and that the eruptions due to the explosion of steam and gases pent up in, or in contact with the magma, are therefore not of the formerly supposed ultra-deep-seated origin. Roccamonfina lies on a great fracture in the Tertiary formations at right angles to the Apennines.

### III. THE VOLCANIC EDIFICE.

The volcanic group proper covers an area of about 200 sq. km., but including the tuffs distributed beyond the limestone belt the area of eruptive products is much larger. Within the belt it is about half that of the Lazio group near Rome, but equal to that of Somma-Vesuvius. Like these two volcanoes, Roccamonfina exhibits the normal contours of two, though not concentric cones, the outer one of which was widely breached on the east. The inner, eccentric cone of S. Croce, about 1·5 km. west of the true centre, formed in the original crater by a later eruption, is roughly rectangular, and with its two wings, one on the south and the other, Mte. Lattani, on the east, measures 10 km. around its base. The depression or corridor between the outer and inner cones, locally called the Pratolungo corridor, and representing the remnant of the original crater 5 km. in diameter, is 1 km. in width, and lies between the steep walls of the inner and outer cones 300 to 400 m. below their

crests. On the eastern side, where the original crater was breached, the depression is more like an open plateau, on the fringe of which stands the town of Roccamonfina at the base of Mte. S. Croce. Of the outer or principal cone, known as Mte. Cortinelli, the western sector alone is fairly well preserved, and rises steeply and uniformly from the River Garigliano<sup>1</sup> (50 m. altitude) for 4 km. up to the Frascara rim, the highest point, at 926 m. altitude, the mean ratio of slope being thus 1 in 4. The northern and eastern slopes towards Mignano and Teano respectively are much more gradual, and do not exceed 1 in 30 to 1 in 25.

On the north and south the original outer cone is broken up into more or less isolated heights and lava flows which crop out from the enormous accumulations of tuff, scoria, and ashes, but are yet sufficiently individual to admit of tracing and reconstructing the great horseshoe with its breach on the east, towards Teano.

Much better preserved is the inner cone of S. Croce, which, rising almost perpendicularly from the old crater floor to a height of 400 m., culminates at an altitude of 1,005 m. and thus forms the highest point of the group. It is connected on the east with the somewhat lower, but petrologically identical boss of Mte. Lattani (817 m.), the two, now almost separated by an eroded glen, constituting originally one craterless cone. In the corridor, along the western or Pratolungo base of this cone, extends an old lacustrine basin 4 km. in length, obviously the remains of a former crater lake of larger dimensions. This was probably blown up by the eruption of the inner cone, the same violent eruption also demolishing the northern, eastern, and southern walls of the outer cone, leaving only the western sector, Mte. Cortinelli, standing. In the reduced lacustrine basin rises a boss of basaltic lava, a product of the most recent period of eruption. The original elevation of both the outer and inner cones was probably in excess of the present one, attenuated by volcanic demolition, atmospheric denudation, and torrential erosion.<sup>2</sup>

#### IV. THE PRODUCTS AND PERIODS OF ERUPTION.

*Lavas.*—The order of superposition of the volcanic products reveals a considerable variety of lavas and therefore of volcanic phenomena, which, however, resolve themselves into three leading types and periods. The first of these are represented by the great outer cone, whose lowest lavas directly overlie the Eocene, and in part Pliocene sedimentary platform. The lavas of that first period are highly leucitic, passing upwards from leucitite to leucite-

<sup>1</sup> The River Garigliano drained originally into the Volturno basin of the Neapolitan Campania, i.e. south-east, but was deflected to the west, i.e. to the Roccamonfina region, by the tuff barrier piled up in the Campania during the eruptions of that volcano.

<sup>2</sup> Moderni's (*op. cit.*) estimate of the original elevation having been 3,000 m., i.e. three times the present one, is obviously exaggerated.

tephrite, with 55 to 58 per cent silica.<sup>1</sup> This first period was therefore marked by a basic magma.

The second period comprises the great eruption of the inner, S. Croce, cone, which demolished the greater part of the outer cone. The typical rocks of this period are biotite-augite-andesite or biotite-trachybasalt of 56 per cent silica,<sup>1</sup> thus being intermediate between trachyte and andesite. But these lavas pass, in the contemporary, isolated and outlying lava flows, to more acid trachyte and leucite-phonolite of 60 per cent silica, of porphyritic structure, with the large so-called "giant" leucite crystals which have long constituted a speciality of the region.

The third and last period is again characterized by more basic, in this case typically basaltic, but non-leucitic lavas, represented by a number of parasitic and outlying cones, of which one rises in the corridor between the outer and inner cones near Mte. Lattani, in the area of the old lacustrine basin previously mentioned. Others, together with isolated lava flows, are scattered all over the volcanic area and overlie on the flanks of Mte. Cortinelli the lavas and tuffs of older eruptions. The progression of the three effusive periods was thus from a basic to a more acid, and then again to a more basic magma, ranging from 55 to 60 and 50 per cent silica respectively, as is shown in the Petrographic Note at the end of this paper.

The first two periods were obviously of great violence and magnitude. The first, in its consecutive phases, built up the great outer cone 800 m. high on the sedimentary platform; the second piled up the remarkable inner cone to 400 m. above the old crater floor in purely effusive and uniformly constituted lava. Preceded by a great explosive eruption of ashes, pumice, lapilli, and scoria, the lava welled up in a pasty, viscous state, and piled itself up on and around the vent, the latter becoming finally plugged through want of explosive energy.

The third period, in part explosive, but mainly effusive, was restricted to short sporadic flows from the central volcano, accompanied by the formation of parasitic and outlying cones; it marked the decline of eruptive activity and gradual cessation of the shifting of the eruptive axis. The length of the lava flows of the first period, with its phases of great explosive and effusive intensity, varies from 4 to 7 km. on the western flanks of Mte. Cortinelli towards the River Garigliano, and up to 4 km. on the northern, eastern, and southern flanks on which the parasitic cones and their products are mainly superposed.

*Tuffs and Breccias.*—The succession of the three principal periods is borne out by the enormous accumulations of tuffs and scoria, often intercalated between the lava flows and vice versa. Except where the lava flows are exposed, the tuffs, like a huge mantle, cover

<sup>1</sup> The S. Croce trachybasalt corresponds to Washington's Vulsinite and Sabatini's trachioligooclase, of the Bolsena and Cimini regions respectively. Amer. J. Geol., 1896, p. 356; Mem. R. Com. Geol., 1912, p. 348.

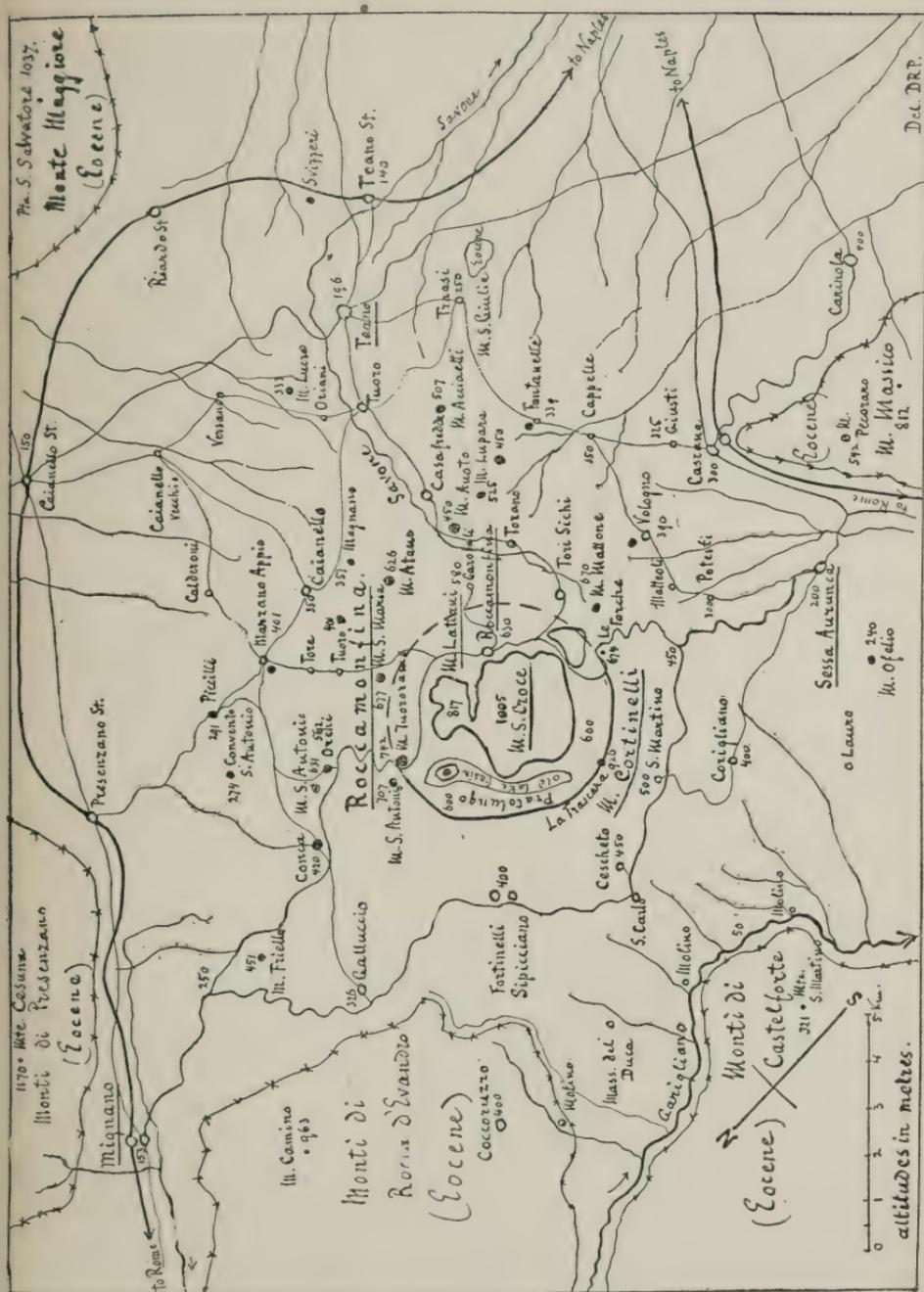
at least four-fifths of the total area of the Roccamonfina group in a radius of 10 km. The lowest, or old grey, leucitic tuffs, often decomposed to clay, overlie the leucitic lavas in the deep-cut gullies of Mte. Cortinelli, and belong to the first period. The upper tuffs, more leucitic and scoriaceous, of characteristic dark grey, blackish colour, are the products of the second period, i.e. of the great eruption which blew up the central crater and covered the whole area with a mantle of ashes which in the eastern ravines attains up to 40 m. in depth, decreasing to 5 to 10 m. on the periphery. It is this tuff which forms part of the upper walls of the great cone. The declining, third period is represented by superficial deposits of coarse breccias of explosive material, which in parts of the area alternate with white earthy tuff, sandy ashes, and pumice, and are strewn with large blocks of lavic material. The grey tuffs of the second period, either as ejected, cemented, and consolidated ashes and scoria, or as mud-flows of retransported lavic and secondary material, not only filled up and blocked the breach of the great horseshoe crater on the east, but on the west and south extended through the gaps of the limestone belt as far as Mondragona on the Tyrrhenian coast, and on the south into the Neapolitan Campania to distances of 25 and 30 km.<sup>1</sup> These dark tuffs as the wind-blown products of Roccamonfina ashes have been met with even east of Naples, as far as Avellino, 80 km. from the seat of eruption. The magnitude of these tuff phenomena thus affords striking evidence at once of the violence of the eruptions and of the potent action of the high winds and torrential rains which invariably accompany them.

As in the majority of other composite volcanoes, so also in Roccamonfina the effusive lavas *in situ* constitute but a small fraction of the combined explosively ejected and secondary retransported products of eruption. Within the volcanic area alone the superficial ratio of lavas to tuffs is approximately 1 : 10, irrespective of the considerably greater depth of the latter which would probably increase the ratio ten and twentyfold, as in other similar regions.

#### V. THE LATERAL CONES AND LAVA FLOWS.

The central constituents of the group within easy access of the town of Roccamonfina, i.e. the great outer cone of Mte. Cortinelli, the inner cone of S. Croce, and the corridor of Pratolungo between them as the remains of the old crater floor, have already been described. Apart from these, the lower flanks of the great cone, as also various lateral parasitic cones and lava flows, may be conveniently studied along the roads which, radiating from Roccamonfina, link it with the peripheral parts of the area, i.e. with Mignano on the north, Teano on the east, Sessa on the south, and the Garigliano Valley on the west. Although these roads run in many

<sup>1</sup> In the Neapolitan Campania, the dark grey Roccamonfina tuff often overlies the old grey "Campania" tuff of the Phlegræan Fields. The latter is of early Quaternary, the former of middle Quaternary age.



parts on tuff, here and there covered with plantation, they strike various cones and lava flows *en route*.

1. Ascending from *Mignano* to *Roccamontina*, the road crosses, about 5 km. from that station, a large flow, 4 km. in length, of leucite-trachyte, which extends north as far as the railway. Soon afterwards it passes the parasitic cone of Mte. Friello with a flow of basalt crossing the road, while several tephritic flows crop out within 1 km. right and left. Further on, between Conca and Orchi, appears a mass of trachyte and east of Orchi a flow of dark grey compact leucite-tephrite. From here the road passes over the old cone wall between the leucite-tephrite and trachyte of Mte. S. Antonio and Mte. Tuororame, and thence descends to the old crater floor, passing the augite-trachybasalt of Mte. Lattani and S. Croce, with the town of Roccamontina at its base.

2. Descending from *Roccamontina* to *Teano*, the road passes, in the crater area, through several outcrops of basaltic lava of the parasitic cone of Mte. Auto, and enters the Savone ravine, whose torrent drains the Roccamontina crater. Near Torano, in the ravine, and throughout the latter down to Casafredda, the tuff banks reach 30 to 40 m. in depth. Near both these places compact grey trachyte crops out from the tuff as an efflux of the parasitic cone of Mte. Atano. Further down, at Tuoro, the road strikes a large flow, 3 km. in length, of leucitite, overlain by the upper, dark tuff; this flow extends to near the town of Teano (196 m.), 2 km. to the north of which, on the road to the Cajanello railway station, crops out a flow of basaltic lava. From Teano the road descends to the railway station of that name. About 3 km. south-west of the latter emerges from the tuff slopes the isolated Eocene limestone hill of S. Giulianoto as conclusive evidence of the sedimentary platform on which the volcanic area of Roccamontina is built up.

3. Proceeding from *Teano* west to *Sessa* along the hill slopes, a mule-path strikes in succession the leucite-phonolite masses of Mte. Acciaetti, the leucite-tephrite outcrop of Fontanelle, the basaltic masses near Cappelle, south of which is a large trachytic and leucite-phonolitic lava flow 4 km. in length, and lastly the porphyritic leucite-phonolite of Valogno, which contains "giant" leucites, and in which Galdieri was the first to notice the presence of hauyne.<sup>1</sup> Basaltic and trachybasaltic lavas also crop out near Giusti and north of Cascano, where the mule path joins the high road to Sessa. All these flows are superposed on the south flank of Mte. Cortinelli, and derived from the parasitic cones of Mte. Acciaetti, Mte. Auto, and Mte. Mattone.

Two other roads of special geological interest are those from Sessa north-east to Roccamontina, and north to Mignano, the former of which ascends, while the latter skirts the western flank of

<sup>1</sup> A. Galdieri, "Hauyna di Roccamontina": R. Acc. Sc. Napoli, 1913, p. 107.

Mte. Cortinelli, passing in succession the products of eruption of the three periods.

4. *Sessa-Roccamonfina*.—Ascending the flank of the Mte. Cortinelli cone the road runs for 4 km. on tuff, scoria, and ashes, and then strikes the great masses of leucite and leucite-tephrite which in large flows extend 4 or 7 km. down to the River Garigliano. The road then passes over a large mass of trachytic lava, then over the leucite-tephrite of Le Fordie (674 m.), i.e. the saddle of the crater wall, here only 80 m. in height, down to the crater floor, and then, skirting the base of the trachybasaltic lava of the S. Croce cone, terminates at Roccamonfina.

5. *Sessa-Mignano*.—This road branches off the Roccamonfina road about 2 km. south of Le Forche, and skirting the flank of Mte. Cortinelli passes for about 8 km. through the great leucitite and leucite-tephrite masses of that cone (among which crop out several trachytic masses), and then crosses the basaltic lava flow of Sippicciano, 3 km. in length. From here it runs over alternating masses of tuff and tephritic lava for 4 km. to Galluccio, and thence over similar alternations for another 4 km. to the junction with the Roccamonfina and Mignano road on the large flow of leucite-trachyte, an efflux of Mte. Friello, previously mentioned.

6. On the north-east, towards the villages of Cajanello and Marzano, several parasitic cones are superposed on the breach of the Roccamonfina crater wall, notably Mte. Atano and Mte. S. Maria, mostly of leucitic, in part overlain by basaltic lava, while more to the north, about 1 km. from the station of Presenzano, a large and several smaller flows of basaltic lava crop out from the grey upper tuff mantle. All the parasitic cones mentioned are more or less worn and denuded by atmospheric agency and torrential erosion.

The fact that in several of the parasitic cones the leucitic, tephritic, and basaltic lavas occur in juxta- or superposition, points to these craterless cones having been formed on fissures radiating from the central crater in connexion with its eruption. The central vent having become plugged by the superposition of the S. Croce cone during the second period, the third or basaltic eruptive phase took place by a shifting of the eruptive axis 2 km. north, but within the central crater floor. The various outlying basaltic cones were probably formed on fissures of the eruptions of previous periods. These fissures have, of course, been partly or entirely obliterated by overlying ashes, tuffs, and scoria, as also by vegetation and denudation.

#### VI. CONCLUSION.

As already stated, the lowest lavas of Roccamonfina rest on an Eocene limestone platform and some Pliocene deposits. The volcanic activity did not begin till the end of the Pliocene, i.e. at the time of the general uprise of the land which succeeded the general subsidence of the early Pliocene. The decomposition of the old grey tuff to clay in the ravines and gullies on the flanks of

Mte. Cortinelli affords evidence that the volcano, in its first period, was, if not actually submarine, certainly surrounded by the sea, which also left traces of its presence at the base of the volcanic group towards the coast. The three principal periods of eruption may be summarized as follows :—

*I Period.*—Late Pliocene and early Quaternary. Submarine and subaerial. Uprise of platform. Formation of the principal cone by repeated eruptions of leucitic lavas and lower grey tuffs.

*II Period.*—Middle Quaternary. Subaerial. Great eruption of central crater; demolition of eastern crater wall; formation of trachytic and leucite-phonolitic lava flows and dark grey tuff mantle; formation of inner, trachybasaltic cone of S. Croce and Mte. Lattani.

*III Period.*—Recent Quaternary. Subaerial. Decline of volcanic activity. Sporadic basaltic eruptions of parasitic cones in centre and on periphery with lava flows and white pumiceous tuffs, sandy ashes, and breccia.

The period of maximum activity was thus the second in middle Quaternary times. The decline and extinction falls in pre-historic times. An allusion by Orosius, the Roman historian (about A.D. 420), to volcanic phenomena near Teano in 269 B.C. does not constitute an authentic record. As an active volcano, Roccamontina was probably the contemporary of its great northern neighbour Lazio, near Rome, and also of its great southern neighbour Mte. Somma, but in their eruptive manifestations the three acted quite independently of each other.<sup>1</sup>

## VII. PETROGRAPHIC NOTE AND TABLES.

Microscopic examination of the principal Roccamontina lavas shows them to be composed essentially of leucitic and non-leucitic rocks, the three eruptive periods being marked by a general passage from a basic to a more acid, and again to a more basic magma, as already stated in a previous paragraph. The leading characteristics of the lavas, more especially those of the outer cone Mte. Cortinelli, the inner cone S. Croce, and Mte. Lattani, and the Pratolungo corridor cone, representing the three consecutive periods respectively, may be shortly stated as follows :—

*I Period, Mte. Cortinelli.* (1) *Leucitite.*—Black to grey, compact, dominantly or wholly composed of leucite with segregations and enclosures of augite, accessory plagioclase and some orthoclase. Groundmass a densely packed aggregate of microl-leucites with intermediate microliths of augite, magnetite, and some lamellar plagioclase. Colourless vitreous base. Silica 55 per cent.<sup>2</sup>

<sup>1</sup> About 100 km. west of Roccamontina lies the volcanic group of the Ponza Islands. They are greatly broken up by the action of the sea. The mainly compact black basaltic lavas have more affinity with those of Roccamontina (III Period) than with those of the Bay of Naples.

<sup>2</sup> The Silica percentages of these lavas substantially correspond with those of the lavas of the Roman volcanoes (Lazio and Etruria).

(2) *Leucite-Tephrite*.—Grey, much altered groundmass as above, but much more plagioclase. Vitreous base with micorfelsitic aggregations due to decomposition. Silica 58 per cent.<sup>1</sup>

*II Period, Mte. S. Croce and Mte. Lattani.* (1) *Biotite-Trachybasalt* (medium Vulsinite).—Dark to pale reddish, rough surface; dominant basic plagioclase and augite with biotite, also some alkali plagioclase and magnetite grains; no olivine. Numerous segregations of the three principal constituents. Augite often altered, discoloured, with black rim. Plagioclase full of vitreous inclusions. Colourless groundmass a dense aggregate of plagioclase microliths. Silica 56 per cent.<sup>1</sup>

(2) *Trachyte*, Sessa, Roccamonfina, Mte. Ofelio-Galluccio Road. Pale to dull grey, rough, compact or scoriaceous. Dominant sanidine and augite with diopside, magnetite, and some plagioclase. Numerous segregations of these minerals. Silica 60 per cent.

(3) *Leucite-Phonolite*, near Mte. Mattone and Valogno. Pale grey or whitish porphyritic structure. Dominant sanidine and augite with large phenos, also segregations of leucite. Dark grey variety with micro-phenos of hauyne; groundmass sanidine, rounded leucite, plagioclase, augite, biotite, and magnetite. Silica 60 per cent.<sup>1</sup>

*III Period.* Pratolungo Corridor Cone: Mte. Friello, etc. *Basalt*.—Black, compact, with phenos and segregations of augite and olivine, biotite and plagioclase. Groundmass dense aggregate of plagioclase microliths, augite, and magnetite, and colourless glass. Greyish brown variety, cavernous; other variety reddish brown, porous. Silica 50 per cent.<sup>1</sup>

The composition of the principal lavas of Roccamonfina is summed up in the following table:—

MINERALOGICAL TABLE.

*e* = essential element.*s* = subordinate element.*a* = accessory element.

Lavas.	SiO <sub>2</sub> per cent.	Vitreous Felspar Sanidine.	Plagioclase.	Leucite.	Augite.	Olivine.	Biotite.	Hauyne.	Magnetite.
1. Leucitite . . . .	55	—	<i>a</i>	<i>e</i>	<i>e</i>	—	—	—	<i>s</i>
2. Leucitite-Tephrite . . . .	58	—	<i>e</i>	<i>e</i>	<i>e</i>	—	—	—	<i>s</i>
3. Biotite-Trachybasalt <sup>2</sup> . . . .	56	<i>s</i>	<i>e</i>	—	<i>e</i>	—	<i>e</i>	—	<i>s</i>
4. Trachyte <sup>2</sup> . . . .	60	<i>e</i>	<i>s</i>	—	<i>e</i>	—	—	—	<i>s</i>
5. Leucite-Phonolite . . . .	60	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>	—	<i>a</i>	—	<i>s</i>
6. Basalt . . . .	50	—	<i>s</i>	—	<i>e</i>	—	<i>a</i>	—	<i>s</i>

<sup>1</sup> The Silica percentages of these lavas substantially correspond with those of the lavas of the Roman volcanoes (Lazio and Etruria).

<sup>2</sup> These non-leucitic lavas correspond with Washington's trachydolerites or Vulsinites (medium and acid respectively), the Roccamonfina trachyte not being as acid as the true trachytes or Toscanites (65 to 75 per cent silica).

*The Roccamonfina Group.*

## CHEMICAL COMPOSITION.

	<i>Leucite-</i> <i>Tephrite.</i> <sup>1</sup>	<i>Biotite-</i> <i>Trachybasalt.</i> <sup>2</sup>
	Per cent.	Per cent.
SiO <sub>2</sub> . . . .	58.48	55.69
Al <sub>2</sub> O <sub>3</sub> . . . .	19.56	19.08
Fe <sub>2</sub> O <sub>3</sub> . . . .	4.99	4.07
FeO . . . .		3.26
MgO . . . .	0.53	3.41
CaO . . . .	2.60	6.87
Na <sub>2</sub> O . . . .	3.14	2.89
K <sub>2</sub> O . . . .	10.47	4.41
Loss by ignition . . . .	0.24	0.17
	—	—
	100.01	99.85
Sp. gr. . . .	2.57	2.71

<sup>1</sup> Of Mte. S. Antonio, north of Roccamonfina; v. Rath, op. cit.

<sup>2</sup> Of Mte. S. Croce, Washington, op. cit.; v. Rath (55.08 per cent, SiO<sub>2</sub>), op. cit.

V.

## The Monte Vulture Group.

- I. INTRODUCTORY.
- II. GENERAL FEATURES.
- III. THE VOLCANIC EDIFICE.
- IV. THE PRODUCTS AND PERIODS OF ERUPTION.
- V. CONCLUSION.
- VI. PETROGRAPHIC NOTE AND TABLES.  
SKETCH-MAP, FIG. 10.

### I. INTRODUCTORY.

MONTE VULTURE is in many respects on the Adriatic versant of the Southern Apennines what Roccamonfina is on the Mediterranean side of that range. Curiously enough, as an extinct volcano it entirely escaped the notice of the ancients; Horace (65 to 8 b.c.), who was born in the neighbouring town of Venosa (Venusia), 16 km. east of Mte. Vulture, only sang the praises of the beautiful "Vulture in Apulo", of the rapid river Ofanto (Anfidus) flowing at its base, and of the amenities of the surrounding vine- and olive-clad uplands.<sup>1</sup> The then dense woods of Mte. Vulture, much more luxuriant than now, obviously concealed from his view the true nature of the ground which even in the case of Mte. Somma he and his contemporaries vaguely guessed but did not realize. Even fifteen centuries later, Luigi Tansillo, another poet and native of Venosa, extolled the beauties of Mte. Vulture without noticing or alluding to its volcanic origin, although by that time the eruptive phenomena of Southern Italy had become the subject of more serious study.

It was not till 1778 that the learned Abbé Domenico Tata published in Naples the first reliable account of Mte. Vulture in the form of a letter addressed to Sir William Hamilton.<sup>2</sup> In this letter he described that mountainous group as an enormous and confused accumulation of volcanic material piled up by eruption after eruption, not unlike Mte. Somma and Vesuvius. An equally valuable, but more detailed and more strictly scientific description was that left in manuscript by the learned Padre Tortorella on his death at Melfi in 1837.<sup>3</sup> These two monographs, distinguished alike by the remarkable intuition and perspicacity of their authors, were followed, in 1851, by Scacchi and Palmieri's classic Report<sup>4</sup> on the

<sup>1</sup> Carm. III, 4: The name Vulture is probably derived from birds of prey infesting the mountain in ancient times, similar to Mte. Volturino, south of Potenza, and Volturara, the name of two towns in South Italy.

<sup>2</sup> Sir W. Hamilton, an ardent naturalist, was at that time British Ambassador to the Court of Naples.

<sup>3</sup> Padre F. Tortorella, science master at Melfi Seminary, 1837. Memoria sulla stato attuale ed autico del Mte. Vulture.

<sup>4</sup> A. Scacchi and L. Palmieri, Regione vulcanica del Mte. Vulture e tremuoto, 14th August, 1851.

disastrous earthquake of Melfi and the neighbouring towns and villages, which in that year shook the eastern flanks of Mte. Vulture. The investigations of the extinct volcano and of the surrounding sedimentary area led these distinguished vulcanological authorities to the conclusion that the catastrophe was of purely sedimentary and tectonic, not of volcanic origin, and that, in fact, seismic phenomena in Southern Italy generally are not the cause but the effect of sedimentary dislocations to which that part of the peninsula has always been, and is still, peculiarly liable.

Besides these three outstanding older works on Mte. Vulture, a number of more recent partial contributions on the subject are notably those by Abich (1839), the first who published a reliable geological map of the region; by Pilla (1838), by Vom Rath (1881), Johnston-Lavis (1886), Ricciardi (1887), and others,<sup>1</sup> until G. de Lorenzo published his memoir of 1901<sup>2</sup> as a sequel to his extensive previous studies of the geological history and structure of Apulia.

Among various fallacious interpretations of the origin and volcanic phenomena of Mte. Vulture figured conspicuously two theories. The first of these was that of Abich, Pilla, and others, who regarded Mte. Vulture, like Roccamonfina, as a typical example of an "upheaved" volcano; the second was that of a fissural connexion between the eruptive centres of Ischia, Vesuvius, Lake Ansantus, and Mte. Vulture, on the ground that these are situated in an approximately straight line (150 km.) west to east. This hypothesis, persistently advanced since 1835 by Daubeny,<sup>3</sup> Ponzi, Scrope, and even by Lyell and Suess down to 1897, has, however, been abandoned, and as early as 1851 was pronounced untenable by Scacchi and Palmieri in their report already quoted, for the simple reason that there is absolutely no evidence of the supposed transverse fissure nor record of those centres having at any time been in simultaneous eruption or having otherwise reacted on each other.

## II. GENERAL FEATURES.

Mte. Vulture stands out conspicuously from the Apulian sedimentary tableland as a solitary majestic volcanic group, about

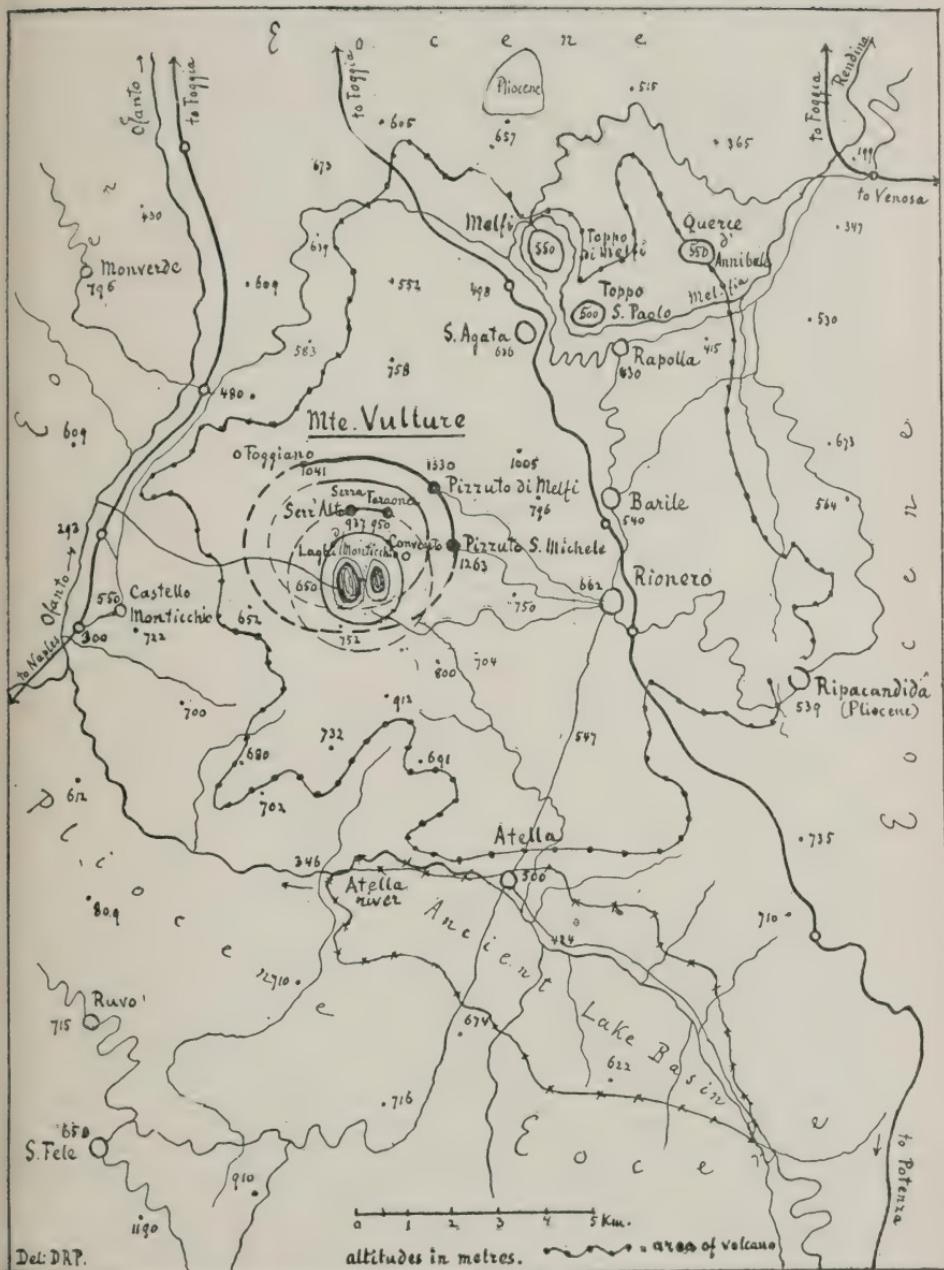
<sup>1</sup> H. Abich, *Vulkanische Erscheinungen und Bildungen in Unter- und Mittel Italien*, 1841. L. Pilla, *Catalogo delle rocce del Mte. Vulture*, 1838. G. vom Rath, *Sitzungsber. Niederrh. Gesellschaft*, 1881. C. de Stefani, *Escursione in Calabria*, 1878-9. H. J. Johnston-Lavis, "Relationship of the Structure of Rocks": *Proc. R.S. Dublin*, 1886. L. Ricciardi, *Sulle rocce e minerali del Mte. Vulture-Melfi*, 1887-9.

<sup>2</sup> Giuseppe de Lorenzo, "Studio geologico sul Mte. Vulture": *Atti R. Acc. Sc. Fis. and Nat. Napoli*, 1901.

<sup>3</sup> Charles Daubeny, *Narrative of excursion to Lake Amsanctus and Mount Vultur*, Oxford, 1835. Lake Amsanctus (d'Ansanto) is by repute a crater-lake basin, with carbonic acid exhalations, and the source of the Mefita, in the Upper Ofanto valley, at 766 m. altitude, 4 km. from the town S. Angelo de' Lombardi, on the Avellino-Foggia railway. It lies about midway between Vesuvius and Mte. Vulture, and is described by Virgil (70-19 B.C.) in *Aeneid* vii, 565.

## The Monte Vulture Group.

Fig. 10.



60 km. inland from the Adriatic coast. It lies in the north corner of the ancient district of Lucania, later called Basilicata, and now the province of Potenza; but topographically it has always figured as part of Apulia. Thanks to the remarkable network of costly railways with which the Italian Government has endowed the whole of Southern Italy, formerly so much neglected, the Mte. Vulture region is now within nine hours' reach from Naples either by Potenza, by Foggia, or by the more circuitous route of Avellino and Rocchetta S. Antonio. The last-named line skirts the volcanic group on the west along the defile of the River Ofanto; that of Potenza skirts it even more closely on the east, passing, by a succession of deep cuttings and tunnels, through the vine-, olive-, and chestnut-slopes of the towns of Melfi,<sup>1</sup> Rapolla, Barile, and Rionero, all of which suffered heavily by the earthquake of 1851. Still more to the east, in the Rendina Valley, lies Venosa (410 m.), on the line from Foggia to Taranto, while on the southern margin of the group stands the town of Atella (500 m.), and on much higher ground on the south-west and west are perched the towns of S. Fele and Monteverde (800 m.).

In the centre of the group lies Monticchio at 650 m. altitude, with its castle and the former great Capuchin convent, the last-named close to the two crater lakes of the same name, separated from each other by a low bank or strip of tuff on which stand the ruins of the ancient monastery of St. Hippolytus. On the south the group is skirted by the River Atella, on the east by the Rendina, affluents of the Ofanto.

The sedimentary platform on which Mte. Vulture is built up is composed of the sequence characteristic of the whole Apulian plateau, i.e. of all the later Mesozoic and the Tertiary formations from Middle Triassic and Cretaceous limestones to Eocene flysch, Miocene molasse, and Pliocene marine conglomerate and sand, overlain in part by Quaternary deposits. The sedimentary outcrops at the base and in the immediate vicinity of the volcanic group are more especially the Tertiary series, of which the flysch and molasse are in evidence all round up to 700 m., and the marine Pliocene conglomerates up to 800 m. above sea-level. In the flysch, overlain by banks of yellow and brown macigno and molasse, are often embedded blocks of older crystalline rocks which now exist in situ only in Calabria and the Tyrrhenian islands. These blocks were probably washed in by the sea and deposited in the flysch then in course of submarine formation.

The Tertiary sandstone platform of the volcanic group is of special interest because, during the eruptions which in their upward course passed through it, it yielded the abundant sand grains and also the sandstone blocks which occur in the sanidinic tuffs of the successive

<sup>1</sup> Melfi was almost entirely destroyed by the earthquake of 1851. Potenza shared the same fate during the earthquake of 1857. Both towns had to be practically rebuilt.

eruptive periods. The Quaternary deposits are represented more especially by two old lacustrine basins, one the Atella basin on the southern margin, the other the Venosa basin on the north-eastern margin of the volcanic group. According to de Lorenzo's view, these two basins afford conclusive evidence of a former continuous post-Pliocene valley which ran south to north and north-east, and whose middle section was the original seat of eruption of Mte. Vulture *ab initio* as a subaerial volcano. On the other hand, the marine Pliocene beds which in the Mte. Vulture group rise to 800 m. altitude, and in other parts of both the Adriatic and Mediterranean versants of the Apennines as high as 1,000 and 1,300 m. altitude, warrant the inference that the Pliocene sea before its retreat washed, if it did not submerge, the margin of the volcano in the latter's initial stage of eruption, as was the case in all the Pliocene-Quaternary volcanoes of the Mediterranean watershed. Mte. Vulture is of the same age, and a phenomenon concomitant with the general post-Pliocene uprise of the Apennines.

The most imposing views of Mte. Vulture are from the Apulian plain and the low hills, notably from Rionero (662 m.), as well as from the isolated Pliocene hill on which stands Ripacandida (662 m.), respectively 4 and 8 km. distant from the crest of the volcano on the east, and from Atella (500 m.), 6 km. distant on the south. The latter view more especially discloses not only the solitary grandeur and entire length of the volcano's five-toothed crest, but the peculiarly graceful, slightly concave, parabolic lines of its slopes, due to the gradual settlement by its own weight, the pressure of which at the same time dislocated and flattened the irregular sedimentary platform.

### III. THE VOLCANIC EDIFICE.

The volcano proper and its eruptive products form a roughly elliptic base of 50 km. in circumference, the minor axis of 10 km. (north to south) and the major of 12 km. (east to west) giving an approximate area of 100 sq. km. This area is less than that covered by Roccamonfina or by the extinct volcanoes around and north of Rome; but the tuffs and mud-flows of Mte. Vulture probably extended considerably into the Apulian plain beyond their present limits, and were in great part removed with the immediately underlying loose Pliocene and Quaternary sedimentary deposits by denudation and erosion which throughout Apulia have always been, and still are, extremely potent and destructive factors.

Built up on its elliptic platform about 500 m. above sea-level, the volcano rises at its two highest points, i.e. in Pizzuto di Melfi and Pizzuto di S. Michele, to 1,263 and 1,330 m. altitude respectively. These two points form the northern and southern extremities of the ridge which, with several intermediate toothed remnants of somewhat lower elevation, constitutes the ruins of the original outer

cone of the group known collectively as Mte. Vulture. This sector, crescent-shaped, 3 km. in length, faces west and clearly indicates the originally elliptic form of the complete cone, whose northern, southern, and western sectors were demolished by later explosions, leaving only a huge breach towards the Ofanto ravine, which skirts the western base. The rim of the great cone must have been over 4 km. at its major and 3 km at its minor axis, as is clearly shown by the elliptic edge of its crater, which runs along the inner wall of the ridge at an altitude of 900 m. or 300 m. below the summit rim or crest.

The violent explosion which blew up the crater floor, breached the cone, and demolished three-fourths of the latter, was probably that of the eruption and formation of the inner, eccentric cone of Monticchio by the shifting of the eruptive axis about 1 km. south of the original crater centre. Of this inner, roughly circular cone, 3 km. in diameter and built up on the original crater floor, the northern sector is formed by the Serr' Alto and the Serra Faraone, about 1,000 m. in altitude, while its eastern sector abuts against the crater wall of Pizzuto S. Michele. In the crater basin 350 and 550 m. below these points respectively lie the two contiguous, more or less circular crater lakes, the greater and the lesser, of Monticchio, about 1 km. in total diameter and 40 m. in depth, at 650 m. altitude or 600 m. below the rim of the original great outer cone. The Monticchio basin is being gradually denuded of its former dense woods and luxuriant vegetation, and the larger of the two lakes is in process of silting up.

The whole eastern, deeply furrowed flank of the Mte. Vulture ridge is, owing to the fine volcanic soil, extremely fertile and richly cultivated. It is on this side of the group that, in its northern part, about 6 km. east from Pizzuto di Melfi, rise the two remarkable lateral cones of Toppo di Melfi and Toppo S. Paolo, 626 and 500 m. in altitude respectively, barely 1 km. from each other. From their petrological characteristics and their relation to the other volcanic products of the group, the latter cone marks one of the earliest, the former, on which stands the town of Melfi, one of the latest eruptive periods of Mte. Vulture. During the successive periods and phases of eruptive activity, other lateral and parasitic cones were probably formed, but they were either demolished in their turn or buried under the products of subsequent eruptions.

As already mentioned, Mte. Vulture was hailed by Abich, on his visit in 1839, as a typical example, like Roccamonfina, of a volcano upheaved *en masse*, the steep crater walls being regarded as proof of a later falling-in of the assumed original domal cupola. This view, at the time ardently espoused by Pilla and others, is contradicted by all the tectonic features of the group which reveal and mark Mte. Vulture as a true double-coned, explosive and effusive, i.e. a composite, albeit in its present denuded and attenuated form, an extremely complex volcano.

## IV. THE PERIODS AND PRODUCTS OF ERUPTION.

The eminently characteristic feature of the lavas and also of the secondary products of Mte. Vulture is their remarkably low basicity, determined by the prevalence not only of augite, but of alkaline minerals, i.e. of leucite, nepheline, and notably of hauyne. These three are present, together with basic felspar, in all the lavas and form in some varieties the dominant constituents, as is more fully shown in the petrographic Note appended to this paper.

The lavas are mainly phonolitic, tephritic, and basaltic, i.e. sanidinic, plagiocasic, and olivinic, with a silica percentage decreasing from 55 to 48 and 42 per cent respectively, and it is this generally decreasing order which marks the sequence of eruptions as represented by the superposition of homogeneous lava flows together with enormous accumulations of clastic, tufaceous material from the base to the crest of the volcano. This superposition admits of defining the eruptive activity of Mte. Vulture as comprising three main periods, in the course of which the fluid or viscous magma became gradually more basic with countless intermediate passages attested by the remarkable variety of the forms of primary and secondary consolidation.

I. The first or earliest (Pliocene-Quaternary) eruption is represented by the phonolitic, sanidinic, more or less pumiceous tuffs which immediately overlie the sedimentary platform and form a fringe or belt up to 100 m. in depth all round the base of the volcano in a radius of 7 km. The largest deposits of these tuffs, as also those of later explosive eruptions, are in evidence more especially on the northern and eastern flanks where they extend to Melfi and several kilometres beyond Rapolla, Barile, and Rionero, while on the south they reach to Atella, and on the west, i.e. on the Monticchio side, crop out, though in a minor degree, above the Eocene and Pliocene formations of the Ofanto defile. A remarkable feature in these phonolitic tuffs are the large blocks of grey hauynic phonolite, which are not only embedded in the tuffs, but scattered among the re-transported alluvial deposits towards Venosa, and also occur near Toppo S. Paolo and Rapolla, and up to 550 m. altitude on the height called Querce d'Annibale (Hannibal's oak-grove),<sup>1</sup> a few kilometres east of Melfi. The fact that they are embedded in the lowest phonolitic tuffs points to their being the ejected or effusive products of a still earlier eruption, probably from a vent, subsequently demolished or now buried, on the eastern flank.

After the explosive phase of the lowest phonolitic tuffs, the first period of eruption was marked by another phase, i.e. that of the eruption of the lateral cone of Toppo S. Paolo (500 m.) on the eastern flank, which is built up direct on the phonolitic tuff, and is, in com-

<sup>1</sup> This wooded height was by tradition occupied by Hannibal on his way to Cannae (near Barletta), about 40 km. east of Mte. Vulture, and after his victory in 216 B.C. again in 215 on his way to Nola and the Neapolitan Campania.

position, closely related to the same. That lava cone, about half a kilometre in diameter, rises from the subjacent tuff to a height of 100 m., and is entirely composed of pale to reddish grey, porous, compact, anorthitic (not sanidinic) phonolite of porphyritic structure, with hauyne, leucite, and augite. The fact that the lava cone presents a solid, homogeneous cliff-like mass is probably due to the magma having welled up from the orifice in a viscous or pasty state, which for want of gas and steam had no explosive power. It is a cone with a plugged vent, precisely analogous to that of Mte. S. Croce, the inner cone of Roccamonfina.

II. The second (Quaternary) period of eruption, of long duration and repeated phases, included the gradual formation of the great outer cone of Mte. Vulture, built up almost entirely of tephritic and basaltic material, the basic felspathoid minerals leucite, nepheline, and notably hauyne being here, too, largely in evidence, together with basic plagioclase and augite, and olivine and augite, as the normal constituents of the lavas respectively. The lava flows of pale grey, compact, hauyne-tephrite in tabular banks and of spheroidal structure are conspicuous more especially on the northern flank and the summit of Pizzuto di Melfi, on the crest above Rionero, and on the southern flank of Pizzuto S. Michele. Leucite-tephrite, on the other hand, constitutes the greater part of the original crater floor of the great cone, where it alternates with basalt, leucitite, and nephelinite, together with breccia and scoria. A variety of grey and reddish-brown andesitic, i.e. highly plagioclastic, tephrite is exposed on the road from Melfi to Rapolla.

To a later phase of the second period of eruption belong the essentially basanitic and basaltic, i.e. the most basic lavas, largely diffused, though less so than the tephritic lavas. They occur in a great variety of forms, among them notably the basanite (plagioclase, olivine, and augite) with leucite and hauyne, of Pizzo S. Agata (636 m.), 2 km. south of Melfi, a compact, porphyritic, spheroidal, reddish-grey lava which is also exposed in the two tunnels between Rapolla and Barile, driven through that lava flow. Reddish-brown leucite-basalt occurs in the lava flow of Acqua Santa and Foggiano, north of the Monticchio crater lakes, on the western margin of Mte. Vulture. A third, almost black, hard, and compact variety is the lava flow on the path from Rionero to Fontana dei Giumentari. Both the tephritic and basaltic lavas pass in some flows to leucitite and nephelinite, i.e. where the two corresponding minerals predominate at the expense of felspar, augite, and olivine. Leucitite as lava is in evidence close to the smaller crater lake south of the Capuchin Convent; nephelinite in the remarkable natural obelisk called Pietro della Scimia, which rises north of the lakes from among the volcanic conglomerates of Serr' Alto and Serra Faraone as a remnant of the original great outer cone of Mte. Vulture.

One of the most instructive and easily accessible natural sections showing the superposition of eruptive products is the one south of

the lakes, on the left bank of the Ufita glen below the Cappella del Priore, where the following sequence is exposed in upward succession :—

- (1) Sedimentary base—yellow Pliocene conglomerate and sand.
- (2) Great mass of yellow pumiceous phonolitic tuff.
- (3) Bands of dark-grey tephritic material (bombs, pozzolana, scoria, etc.).
- (4) Band of grey tuff.
- (5) Tephritic and basaltic lava.

Another instructive exposure is that at Fontana dei Giumentari, where no less than five tephritic and basaltic lava bands alternate with as many intermediate bands of tuff, breccia, and scoria, thus showing the succession of effusive and explosive phenomena in the repeated phases of eruption.

The height to which the great outer cone of Mte. Vulture was raised from the subjacent phonolitic tuff base (600 m. altitude) to the present summit of the crest (1,300 m.) during the successive explosive and effusive eruptions of the second period was 700 m. or more, the originally higher crest having been in part lowered by later erosion and denudation.

III. The third (Quaternary) period of eruption was marked by a violent paroxysm which, as previously mentioned, demolished three-fourths of the great cone by the explosion of the eccentric crater of Monticchio, formed in the southern part of the old crater floor, about 1 km. from the true centre. As the effect of this explosion, a new inner cone was piled up, of which Serr' Alto and Serra Faraone formed the northern, and Pizzuto S. Michele the eastern crater wall, the new crater floor being now occupied by the two lakes. These represent two juxtaposed vents of collectively elliptic outline at 650 m. altitude, or 300 m. below the northern sector of the inner cone, composed almost entirely of the blown-up material of the great outer cone and the southern part of its crater floor.

A last phase of eruptive, both explosive and effusive, activity of the Mte. Vulture group was that marked by the lateral cone or "Toppo", on which stands the town of Melfi at 550 m. altitude, on the margin of the north-eastern flank of Pizzuto di Melfi, 6 km. from the latter, and only about 2 km. north of the Toppo S. Paolo cone. The Melfi cone is for the greater part of its base encircled by the Melfia torrent, an affluent of the Rendina which discharges into the Ofanto. Travertin and other lacustrine deposits afford evidence of the cone having erupted from a lake basin (about 2 by 1 km.), formed by the Melfia being banked after the formation of the S. Paolo cone in one of the earliest eruptive phases of the group. The Melfi cone, 1·5 km. in area, presents, like its neighbour, a solid homogeneous boss of lava which, resting on its tuffs about 100 m. in depth and the subjacent Eocene flysch, rises to a height of 50 m.,

the irregular elliptic cupola, flattened by erosion, forming the site of the wall-girt town.

For a long time the Melfi cone was, petrologically, the best known part of the Mte. Vulture group, owing to its celebrated hauynic lava or hauynophyre, more properly hauynite, first pointed out by Brocchi in 1820<sup>1</sup>—a greyish white to reddish and black generally compact basaltic lava studded with countless grains and crystals of black, blue, and red hauyne, which determine the colour of the rock. The dominant alkaline minerals mark the Melfi lava as the point of lowest basicity (42 per cent silica) of the Mte. Vulture group. Its columnar structure is well exposed in the quarries below Melfi castle, while large blocks with spheroidal surface are accumulated around the town walls, and also in the bed of the Melfia torrent. The Melfi lava cone was formed, like that of S. Paolo, by a purely effusive outflow piled up around and over the orifice after the explosive formation of the underlying tuff bed.

IV. The tuffs of the Mte. Vulture group, both primary and secondary, are, like the lavas of the three periods of eruption, phonolitic, tephritic, and basaltic. The first of these constitute, as previously stated, the volcanic marginal base, while the second and third make up by far the larger part of the great cone as compared with the lava flows. All these are the primary products of ejected materials cemented to breccia, and frequently contain, besides bombs and scoria, sedimentary rock fragments and blocks torn by the uprising magma from the Tertiary formations through which it passed or in which it was for a time imprisoned. The tuffs of Serr' Alto and Serra Faraona, on the other hand, which form in part the crater wall of the Monticchio cone, are heterogeneous re-cemented agglomerates of the lavas and tuffs of the demolished great cone. The other secondary tuffs, mud-flows, and retransported products fill most of the glens radiating from the volcano, while the wind-blown ashes and sand ejected by the eruptions were carried as far as 40 and 60 km. to the Adriatic coast.

V. Among the indirect products of Mte. Vulture figure not only the travertin banks, still in course of formation, and the mineral springs of Monticchio, but the limno-volcanic deposits of the depressions formerly occupied by the two lacustrine basins previously mentioned.<sup>2</sup> The first of these lakes, in the Atella or Gando basin on the southern margin of Mte. Vulture, must have been formed during an early period of eruption which blocked the drainage-outlet of the old valley; while the second or Venosa basin at the north-eastern base of the group was, according to de Lorenzo, the effect of the settlement of the volcano and its sedimentary platform. In both depressions secondary volcanic material is mixed

<sup>1</sup> G. Brocchi, "Laziolite in una lava del Monte Vulture": Bibl. It., xvii, p. 261. "Laziolite" is a Lazio tephrite with some hauyne.

<sup>2</sup> In his geological and glacial studies of the Basilicata, de Lorenzo found no less than twenty extinct lake basins.

with sedimentary and lacustrine deposits, and in both cases the lakes gradually emptied themselves by the River Atella of the southern, and the Rendina of the northern basin finding new outlets northward into the River Ofanto.

#### V. CONCLUSION.

Apart from the great intrinsic geological interest of Mte. Vulture as a solitary volcanic group on the Adriatic versant of the Southern Apennines, and of its general analogy with Roccamonfina on the Tyrrhenian watershed, the examination of its lavas sheds an instructive light on the infinite variety, passages, and combinations of their mineralogical structure and composition, evolved from their comparatively simple chemical constitution comprising, as a rule, not more than ten compound components. They show that the mineralogical structure and composition of volcanic rocks is determined only in a minor degree by the chemical constitution of the magma, and pre-eminently by molecular attraction, crystallographical affinity and aggregation, and all the other conditions of consolidation; and this applies equally to internal primary consolidation at the seat of the fluid or viscous magma, i.e. before eruption, and to secondary consolidation during or after eruption.

On the other hand, the chemical constitution, more especially the degree of acidity or basicity, affords an important criterion as to the origin of the magma. Apart from the remarkable basicity of the products of eruption of Mte. Vulture (55 to 42 per cent silica), their most prominent feature is the abundance of hauyne, so much so that this extremely basic mineral of 32 per cent silica is not only a dominant constituent of the lavas, but in the case of the Melfi cone actually forms hauynite. Indeed, Mte. Vulture may justly claim the unique distinction of being essentially a "hauyne" volcano. This extraordinary phenomenon can only be ascribed to the magma having been, at its seat, potently impregnated with infiltrations either of sea-water, or of highly alkaline solutions from contiguous rock formations. In either case the seat of the molten material could not have been at great depth, probably not more than 1,000 or 2,000 m., below the surface of the Tertiary sedimentary platform.

#### VI. PETROGRAPHIC NOTE AND TABLES.

The characteristic features of the Mte. Vulture lavas are: (1) the presence in them all of hauyne as essential element; (2) the gradually decreasing presence of felspar, compensated by increase of augite and the felspathoid minerals, leucite, nepheline, and hauyne; (3) holocrystalline, porphyritic, or microlithic structure, vitreous base and interpositions; (4) frequent occurrence of parallel fluidal bands of different lavas passing into each other; (5) basicity ranging from 55 to 42 per cent silica. In this order of basicity, corresponding

to the sequence of the periods of eruption, the leading features of the principal and typical lavas may be shortly stated as follows :—

### *1st Period of Eruption.*

1. *Hauyne-Phonolite*, in blocks embedded in oldest tuffs or strewn on lower flanks and hills. Grey groundmass of minute crystals with vitreous interpositions, often microfluidal structure. Large phenos of sanidine, some plagioclase, small augites, abundant hauyne in small phenos, accessory titanite, biotite, and magnetite. In groundmass microliths of essential minerals.  $\text{SiO}_2$  55 per cent.

2. *Hauyne-Anorthite-Phonolite*.—Toppo S. Paolo cone. Reddish grey, compact, porous; rich in phenos of anorthite in place of sanidine, also oligoclase; augite with segregations of these. Hauyne abundant, leucite subordinate, some garnet, biotite, apatite, and magnetite.  $\text{SiO}_2$  53 per cent.

### *2nd Period of Eruption.*

3. *Hauyne-Tephrite*.—South and north flanks of great cone; south of Pizzuto S. Michele and on crest above Rionero. Pale grey, compact, in flows and banks with spheroidal surface structure. Groundmass plagioclastic and augitic, very little vitreous base; phenos and segregations of plagioclase and augite; abundant hauyne; leucite subordinate; apatite and magnetite; some hornblende.  $\text{SiO}_2$  50 per cent.

4. *Leucite-Hauyne-Tephrite*.—The most diffused of the lavas; forms greater part of crater wall of great cone; large masses also on Pizzuto di Melfi, alternating with basaltic lava and breccia. Two varieties (1) on Pizzuto di Melfi, dark, leucitic; (2) on Melfi and Rapolla road, pale grey and reddish brown. Both varieties compact, vesicular; phenos of leucite, hauyne, and augite with biotite and apatite. Groundmass plagioclase, augite, and leucite. Hauyne-phenos red, blue, grey, and white, also as inclusions. Frequent bands of fluidal structure.  $\text{SiO}_2$  50 per cent.

5. *Leucite-Hauyne-Basanite*.—Comparatively subordinate; two varieties: (1) Pizzo S. Agata, south of Melfi, pale, reddish grey; (2) here and there in crater of great cone, also in tunnels between Rapolla and Barile. Groundmass olivine, augite, plagioclase, leucite, hauyne, some nepheline; olivine phenos peach green and yellowish red; rich in magnetite and apatite; segregations of essential elements.  $\text{SiO}_2$  48 per cent.

6. *Leucite-Basalt*.—The most diffused next to tephritic lava. Olivine, augite, leucite, and hauyne, with accessory plagioclase and nepheline. Three varieties, each with frequent fluidal bands of other varieties. (1) On Pizzuto di Melfi and Fontana Piloni, in massive flows, dykes, and veins. Groundmass with phenos of

olivine, augite, leucite, biotite, magnetite, apatite, and titanite ; also segregations of essential elements. Very little plagioclase.  $\text{SiO}_2$  48 per cent. (2) Lava flow of Acqua Santa-Foggiano, north of lakes. Grey, almost aphanitic ; vesicular and porous. Essential elements as (1), but with more plagioclase. This lava marks a passage to basanite and tephrite.  $\text{SiO}_2$  48 per cent. (3) Fontana dei Giumentari. Almost black, the darkest of all the lavas, compact, hard. Groundmass of microliths of essential elements (1) and (2) ; vitreous leucite ; some plagioclase and biotite. Phenos of essential elements disseminated in groundmass.  $\text{SiO}_2$  48 per cent.

7. *Leucitite* in individual flows, veins, and in fluidal bands of other lavas. South of Convent S. Michele near small lake, dark grey, compact, sometimes altered. Groundmass leucite, augite, and nepheline, with segregations of these ; accessory biotite, plagioclase, apatite ; hauyne in small phenos full of inclusions.  $\text{SiO}_2$  44 per cent.

8. *Nephelinite*, on road from S. Michele Convent to Padale, emerging from conglomerates of Serr' Alto and Serra Faraona ; natural obelisk Pietro della Scimia, part of demolished great cone. Dark grey, compact, hard, microlithic groundmass with phenos of nepheline, augite, leucite, hauyne, and biotite. Distinct passage from first to second, i.e. pheno- to micro-crystalline consolidation.  $\text{SiO}_2$  44 per cent.

### *3rd Period of Eruption.*

Tuffs and Brecoias of the Monticchio eruption, Serr' Alto and Serra Faraona.

9. *Hauynite*.—Melfi cone. Compact and hard, black to greyish-white lava ; difference of colour determined by colour of hauyne and marked fluidal band structure. Hauyne in countless grains and small phenos, filling groundmass ; augite and large phenos of leucite ; also zeolites, i.e. nosean, sodalite, etc.  $\text{SiO}_2$  42 per cent.

According to Washington's classification of the trachybasalts of S. Etruria, the Mte. Vulture non-leucitie lavas (1 to 3) would come under the category of Ciminites, i.e. basic lavas up to 60 per cent silica. Acid lavas, i.e. true trachytes, andesites, and the still more acid quartzose riolites and dacites from 60 to 75 per cent silica (Washington's Toseanites) are entirely absent in the Mte. Vulture group. The tuffs of that group vary in silica from 40 to 45 per cent, pozzolana from 37 to 39 per cent. The mineralogical composition of the principal Mte. Vulture lavas described in the foregoing Note may be seen at a glance from the following table, which also gives the adventitious minerals and the average silica percentages.

## MINERALOGICAL COMPOSITION.

*e* = essential element.*s* = subordinate element.*a* = accessory element.

Periods of Eruption.	Lavas.	SiO <sub>2</sub> p.c.	Vitreous Felspar.		Felspathoids.		Olivine.	Augite.	Adventitious Minerals.
			Sanidine.	Anorthite.	Plagioclase.	Leucite.			
I.	1. Hauyne-Phonolite . . . .	55	<i>e</i>	<i>s</i>	<i>s</i>	—	—	<i>e</i>	<i>e</i>
	2. Hauyne-Anorthite-Phonolite (S. Paolo) . . . .	53	—	—	<i>e</i>	<i>s</i>	<i>a</i>	<i>e</i>	<i>e</i>
II.	3. Hauyne-Tephrite . . . .	50	—	—	<i>e</i>	<i>s</i>	<i>a</i>	<i>e</i>	<i>e</i>
	4. Leucite-Hauyne-Tephrite . . . .	50	—	—	<i>e</i>	<i>e</i>	<i>a</i>	<i>e</i>	<i>e</i>
III.	5. Leucite-Hauyne-Basanite . . . .	48	—	—	<i>e</i>	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>
	6. Leucite-Basalt. . . .	48	—	—	<i>s</i>	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>
	7. Leucitite . . . .	46	—	—	<i>e</i>	<i>s</i>	<i>s</i>	<i>e</i>	<i>e</i>
	8. Nephelinite . . . .	44	—	—	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>
	9. Hauynite (Melfi)	42	—	—	<i>e</i>	<i>e</i>	<i>e</i>	—	

## CHEMICAL COMPOSITION.

The abnormally low basicity of the Mte. Vulture lavas is due to the abundant presence of hauyne. The following analyses are typical of the two extremes, i.e. Hauyne-Phonolite (55 per cent silica) and Hauynite (42 per cent), the composition of the other lavas being intermediate between those two.

	Hauyne- Phonolite. Per cent.	Hauynite of Melfi. <sup>1</sup> Per cent.
SiO <sub>2</sub> . . . .	55.28	42.46
Al <sub>2</sub> O <sub>3</sub> . . . .	17.75	18.49
FeO and Fe <sub>2</sub> O <sub>3</sub> . . . .	10.60	9.66
CaO . . . .	5.24	8.70
MgO . . . .	2.42	3.64
Na <sub>2</sub> O . . . .	5.86	8.12
K <sub>2</sub> O . . . .	1.72	5.58
SO <sub>3</sub> . . . .	1	2.44
P <sub>2</sub> O <sub>5</sub> . . . .	0.25	0.41
	100.12	99.50

<sup>1</sup> Rammelberg, 1860; P<sub>2</sub>O<sub>5</sub> added by Ricciardi (G. de Lorenzo, op. cit.).

## VI.

### The Phlegræan Fields.

- I. INTRODUCTORY.
- II. GENERAL FEATURES.
- III. THE VOLCANIC PHENOMENA.
- IV. THE CRATER GROUPS.
- V. THE PRODUCTS OF ERUPTION.
- VI. CONCLUSION.
- VII. PETROGRAPHIC NOTE AND TABLES.  
SKETCH-MAP, FIG. 11.

#### I. INTRODUCTORY.

THE region of the “pyriphlegeton” or burning fields, which flanks the bay and city of Naples on the west, as Vesuvius does on the east, has played an important part in the vulcanological history of Southern Italy ever since that famous littoral was first colonized by Hellenic settlers. Before it came under Roman sway in the third century B.C. it was dreaded as the impenetrable abode of Titans and Cyclops and the scene of their battles of “flame and fire”; in early Roman times it was by repute the seat of the infernal regions, and in early Christian times the place where Christ entered Hades. The gay and fastidious Romans of the Imperial era, who had their sumptuous villas on the luxuriant sea-board, despised the “burning fields” as being beyond the pale of civilization, insalubrious, and inhabited only by barbarians; and the popular suspicions attaching to the region were not dispelled till it was opened up by public works. Among these were notably the drainage tunnels, canals, road and harbour works constructed by Agrippa (63–12 B.C.) under Augustus, and later by Domitian (A.D. 51–96), e.g. the Grotto and Sejano tunnels of the Posillipo ridge, the harbour works and canal of Baia, the drainage tunnel of Torre Gaveta, the Arco Felice, the Via Cumana right across the region, and others. Horace, Virgil, Ovid, Juvenal, and other Latin poets, as well as Strabo (60–20 B.C.) all decanted on these works and the beauties and luxury of the Roman seaside.

The volcanic nature of the region is not mentioned till the fifteenth century, i.e. incidentally in Bartolomeo Fazio’s account of a Royal hunt in the Astroni crater, while Niccolo Braucci in 1767,<sup>1</sup> and Sir William Hamilton in 1776,<sup>2</sup> gave the first scientific descriptions of the region. Later, in 1798, Breislak<sup>3</sup> published his work on the

<sup>1</sup> Niccolo Braucci, *Istoria naturale della Campania*, 1767.

<sup>2</sup> Sir W. Hamilton, *The Phlegræan Fields*, 1776.

<sup>3</sup> S. Breislak, *Topografia fisica della Campania*, 1798.

Neapolitan Campania, followed by L. von Buch in 1806,<sup>1</sup> propounding his volcanic upheaval theory which A. Scacchi disproved in 1849.<sup>2</sup> Among the more numerous recent contributions are notably Johnston-Lavis' study in 1895 of the Pianura crater,<sup>3</sup> Gunther's physio- and hydrographic investigations of 1897,<sup>4</sup> and Deecke's geological guide of the Campania of 1901,<sup>5</sup> followed in 1902 by de Lorenzo and Riva's memoir<sup>6</sup> on the Astroni crater group, the first of a contemplated series of monographs on the whole region, a work unfortunately interrupted, or abandoned, through the untimely death of the last-named rising young geologist in the Alps.<sup>7</sup>

## II. GENERAL FEATURES.

The Phlegræan region comprises not only the "burning fields" as part of the Neapolitan Campania, but also the "burning islands" of the Bay of Pozzuoli, the combined, roughly circular area of 7 km. radius being over 150 sq. km.,<sup>8</sup> of which the "fields" occupy about two-thirds. It forms part of the great volcanic area of 80 by 30 km., or 2,400 sq. km., which comprises the Bay of Naples, Ischia, Vesuvius, and the whole Campania. The soil of that famous plain, though not directly volcanic, is to a depth of 50 m. entirely composed of volcanic ashes, other ejecta, and secondary volcanic mud-flows, to all of which the region owes its exuberant fertility. The whole area lies in a zone of early Pliocene subsidence extending from the Sorrento promontory, 30 km. south-east of Naples, to Mte. Massico and Mte. Maggiore, 50 km. north-west of that city. Between those two sedimentary extremities the Cretaceous and Tertiary formations dip to so great a depth that the deepest borings for artesian wells in and around Naples down to 480 m. reached the subsided sedimentary floor only at 430 m. below the surface. The entire trough or syncline is filled with trachytic lavas and other products of Pliocene submarine eruptions. Towards the end of the Pliocene, and in the early Quaternary period, these lavas and ejecta were gradually raised and, emerging from the retreating sea, became the platform of the Quaternary, subaerial, and independently active volcanoes of Vesuvius and the Phlegræan Fields. The island

<sup>1</sup> L. von Buch, *Gesammelte Schriften*, 1806.

<sup>2</sup> A. Scacchi, *Memorie geologiche sulla Campania*, 1849.

<sup>3</sup> H. J. Johnston-Lavis, "Antico Lago di Pianura": *Boll. Soc. geol. It.*, 1895.

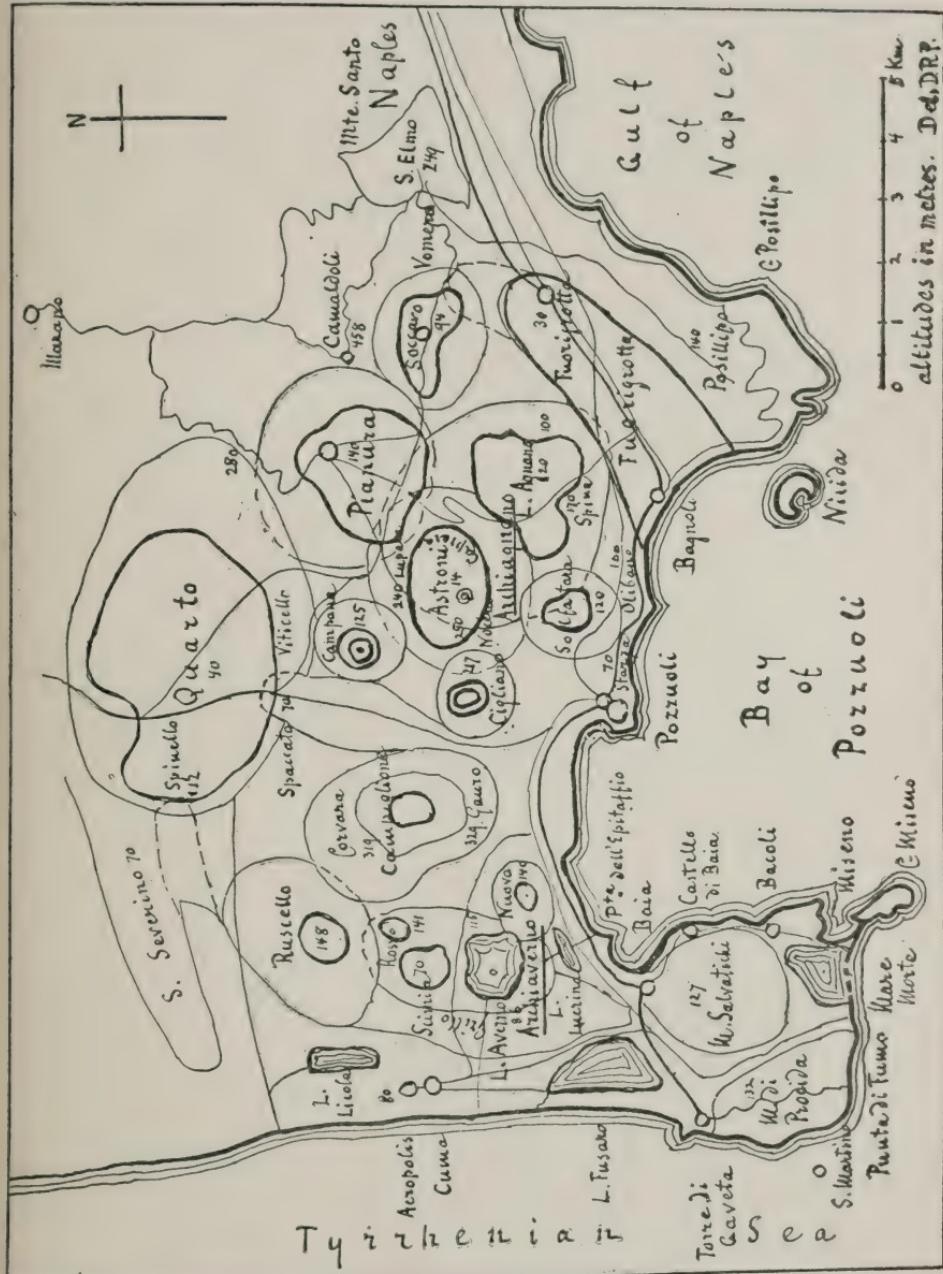
<sup>4</sup> W. Deecke, *Geol. Führer durch Campanien*, 1901.

<sup>5</sup> R. T. Gunther, "The Phlegraean Fields": *Geogr. Journal*, R.G.S., 1897.

<sup>6</sup> G. de Lorenzo and C. Riva, "Il Cratere di Astroni": *Atti R. Acc. Napoli*, 1902, No. 8.

<sup>7</sup> A very instructive contribution is also the relief model of the Phlegræan Fields by Amadeo Aureli, of the R. Ufficio Geologico, Rome, exhibited in the South Kensington Museum, London, in the Dublin Museum, and in many other Museums. *Vide* the photographic reproduction at the end of this volume.

<sup>8</sup> Including the hills of Naples which form the eastern flank of the Camaldoli cone, the Phlegræan area is nearly 200 sq. km.



volcanoes, on the other hand, built up at much greater depth on the subsided floor of the former Tyrrhenian Continent, were gradually raised as submarine cones, partly by Quaternary earth movements, partly by the accumulations of their own products of eruption. After emerging from the sea, these island volcanoes and their later eruptions became subaerial, like those of Vesuvius and the Phlegræan Fields, the three groups being intermittently, probably alternately, active, but quite independently of each other, throughout the Quaternary period and down to historic times.

### III. THE VOLCANIC PHENOMENA.

Of the enormous volcanic area all around Naples, on land and sea, Vesuvius and the Phlegræan Fields constitute *per se* relatively small areas of 100 sq. km. each. In contrast to the great single high-altitude vent of the former, the latter exhibit a multiplicity of no less than fifteen to twenty low cones and craters disposed in clusters or groups within a circumference of 25 km., open to the Bay of Pozzuoli and the Tyrrhenian Sea. In this semicircular area are not included the Baia peninsula, nor the islands of Nisida, Miseno, Procida, and Ischia, which, as previously stated, form the outer volcanic units of the Phlegræan region. Although the Fields proper lie within barely 20, 30, and 50 km. of the volcanic centres of Ischia, Vesuvius, and Roccamonfina, west, east, and north respectively, there is no record of their simultaneous eruption. The magmatic sources or reservoirs of these groups must therefore be either separated from each other by underground rock formations acting as barriers, or they must have found alternate outlets when the vent or vents of either of the groups were temporarily plugged.

The fact that the groups differed considerably in the character of their eruptive activity militates against a magmatic intercommunication between them, at least as regards Vesuvius and the Phlegræan region, the fundamental contrast between these two being conclusive. Vesuvius exhibits all the characteristics of a great double-ringed, composite volcano, with both explosive and effusive eruptions, which have piled up a mountain 1,300 m. high through a single central chimney fed from a vast magmatic reservoir of tremendous explosive force and lifting power. The Phlegræan Fields, on the other hand, are characterized by a multiplicity of relatively low craters, which extend from the sea inland for 10 km., gradually rising, like an amphitheatre, to 450 m. altitude in the Camaldoli cone, the most important volcano of the region. Their eruptive activity has been almost wholly explosive, i.e. productive mainly of tuffs, while lavas, as effusive products, are, with some exceptions, merely sporadic and relatively insignificant. The large area of distribution of the ejecta over the surrounding Campania plain indicates considerable violence of the explosions, reinforced by the carrying power of torrential rains and high winds, but the low

elevation of the cones and craters and the paucity of lava point to a relatively smaller magmatic reservoir than that of Vesuvius.

A further striking characteristic of the Phlegræan Fields consists in the suddenness and rapidity, but withal brief duration of the spasmodically explosive eruptions, as illustrated by the sudden formation of the Mte. Nuovo cone in Pozzuoli Bay in 1538. This phenomenon supplies the key to the formation of most of the cones and craters of the region in Quaternary and prehistoric times, the only exceptions being the two most important cones of Camaldoli and Astroni, built up by repeated eruptions. The spasmodic action, followed by extinction or a long period of quiescence, indicates a shifting of the eruptive axis every time the vent of a crater became blocked, and the explosive gases and steam beneath, of insufficient force to blow it up and form a second cone, had spent themselves or had to seek another outlet.

Hence the further phenomenon, peculiar to the Phlegræan Fields, that the volcanoes are, with only three exceptions, not concentric, but single-ringed cones, often with closed-in, unbreached craters. On the other hand, a feature common to all the three groups of Neapolitan volcanoes is their direct correlation to the adjacent sea, whose infiltrations, when they come in contact with the molten magma, constitute, by the generation of gases and steam, potent agents of explosive eruptions. In the Phlegræan Fields, apart from the direct effect of sea-water by increasing the basicity of the products of eruption, the explosive action was violent enough to blow up the platform and pulverize it or the magma to ashes, scoria, lapilli, and bombs as ejecta, but not sustained enough to produce, lift, and vomit continuous lava flows. In fact, most of the Phlegræan volcanoes were, like Mte. Nuovo, formed by the blowing up and pulverizing of the trachytic platform and the tuff deposits accumulated on the same by older eruptions.

#### IV. THE CRATER GROUPS.

The Phlegræan Fields are conveniently reached from Naples by the Cumana railway along the littoral of Pozzuoli Bay, whence roads lead northward and inland, passing most of the craters. The most comprehensive view of the region is the one from the well-known monastery of Camaldoli, on the summit of the cone of that name, 458 m. in altitude, the highest point of the western outskirts of Naples, from which the various crater groups, spread out below, produce an effect not unlike that of the craters of the moon.

The cones and craters wholly or partially preserved are shown in the sketch-map Fig. 1 and the photograph Fig. 17. They may be considered under the following heads:—

1. The Camaldoli or Northern Group.
2. The Agnano-Astroni or Eastern Group.
3. The Averno or Western Group.

The three groups, with their outliers and extensions, are flanked on the west and east by the two volcanic ridges of S. Severino and Posillipo respectively. These, together with the Camaldoli group which links them on the north, may, in the present writer's view, be regarded as constituting the great outer, semicircular ring or original crater wall of the Phlegræan Fields proper, 12 km. in diameter, breached on the south by the Bay of Pozzuoli.<sup>1</sup>

Owing to the want of compactness of the superficial tuffs, the Phlegræan Fields have greatly suffered from torrential denudation and erosion in the direction of the sea. The greater part of the surface-water sinks into the permeable soil or, when in flood, deeply furrows the flanks of the cones and craters, thus transporting enormous quantities of loose material. Several of the large and flat crater floors were formerly shallow lake basins, which collected the drainage of the closed craters; but with the exception of Lake Averno, all those lakes have either dried up or have been drained artificially, in several cases by extensive tunnelling. On the whole, the Phlegræan Fields, although abounding in fertility and vegetation due to the fine volcanic surface soil, are a poorly watered region, and in the exposed parts atmospheric denudation is therefore all the more active. The best preserved cones and craters are the most recent ones, with more or less clearly defined contours, while the older ones or remaining segments of the same are generally recognizable by the difference between the steep angles of the inner or crater slopes of 30 degrees and more, and the flatter angles of the outer or cone slopes up to 20 degrees. In the course of successive periods of eruption, some of the older craters were either demolished wholly or in part, or overlapped by more recent cones, a phenomenon of superposition important as a criterion of the relative ages and the sequence of eruptions. Of this the Phlegræan Fields afford a number of instructive examples, as will appear in the sequel. The outstanding features of the three groups with their outliers are succinctly described in the following paragraphs.

### 1. *The Camaldoli Group.*

The three contiguous crater basins of this, the most northerly and oldest group of the region, are those of Quarto, Pianura, and Soccavo, disposed on an axis running north-west to south-east. Except the trachytic lava in the lower part of the wall which divides the Pianura from the Soccavo crater, the walls of all the three basins are composed of tuffs and other volcanic ejecta.

*The Quarto basin*, in size the largest crater, roughly elliptic, 5 by 4 km., is closed in by tuff walls varying from 100 to 300 m. in altitude, the lowest on the west, the highest on the divide of its

<sup>1</sup> The Bolsena crater (represented by the crater lake of that name), of the Vulsini region north of Rome, has the same diameter of 12 km.; both bear much analogy to the great Krakatoa crater in the Java islands.

eastern neighbour, the Pianura basin. Its southern wall is on the outside impinged upon by the remaining segment of the Mte. Spaccato crater wall (70 m.) of yellow scoriaeous tuff, and is here cut by the Via di Campania which traverses the whole region south to north from Pozzuoli to Quarto. A similar segment, the Spinelli ridge, overlaps the western base of Quarto, and is the remnant of a large crater basin on the western periphery of the region. After its extinction, the Quarto crater basin became a shallow lake (40 m. above sea-level), gradually drying up, and was finally drained by a tunnel through its western wall (112 m.) and a canal 5 km. in length, which discharges into the Tyrrhenian Sea by the Foce di Licoli.

*The Pianura crater*, separated from Quarto by a joint wall 200 m. in altitude, is, at its floor, irregularly elliptic, 2 by  $1\frac{1}{2}$  km. It is one of the best known craters of the region, its eastern sector being formed by the precipitous crater wall of Camaldoli, the highest point of the Phlegræan Fields. The outer or eastern flank of that wall expands from the narrow ridge to a fan-shaped cone 7 km. in length, sloping gradually down to the plain and bay of Naples, and forming the well-known hills in and around that city, Vomero, Mte. Santo, St. Elmo, Capodimonte, Pizzofalcone, etc. Like Quarto, the Pianura basin was formerly a closed-in shallow crater lake, until a deep-cut drainage exit was formed along the Pignatiello spur of Camaldoli into the adjoining, lower Soccavo basin, and through the latter, to the much lower Fuorigrotta plain with efflux to Pozzuoli Bay. The Camaldoli wall, composed of piperno lava and overlying grey and yellow tuff banks and pozzolana, with intermediate banks of breccia, i.e. varicoloured conglomerate, is 300 m. in height, the Pianura crater floor being 160 m. and the monastery on the summit 458 m. in altitude. The piperno lava is extensively quarried, in part underground, both in the Pianura and the adjoining Soccavo basin, and in both of them the base of the crater wall is thickly strewn with trachytic lava blocks and tuff débris fallen from the cliff. The southern, much lower wall of the Pianura basin is impinged upon by the adjoining Agnano crater; upon this is, in part, superposed the Astroni crater, which also projects into the Pianura basin, a twofold superposition being thus in evidence, fixing the sequence of formation of the three cones and craters.

The great Camaldoli cone, 3 km. in diameter at its rim, slopes from the cliff as its eastern segment, 458 m. in altitude, down to 300 m. on the north and west, and to 200 m. on the southern segment. The crater floor (160 m.), having been raised by repeated eruptions, is at a considerably higher level than the floors of most of the other volcanoes of the region. The great eastern slope of the truncated cone on the side of Naples, covering an area of 30 sq. km. or one-third of the Phlegræan Fields, shows the volcano to have been in size and height inferior only to Vesuvius and Epomeo (Ischia). The repeated eruptions of the Camaldoli crater supplied the yellow and the pozzolana tuff deposits not only of the hills of Naples, but

of those in the other parts of the region, where they were blown up and re-deposited during the formation of the various more recent cones and craters of which they now form part.

*The Soccavo crater basin*, not more than  $1\frac{1}{2}$  by 1 km., is closed in on the north by the Camaldoli wall, on the west by the Pignatiello spur of Camaldoli, and on the east by the Vomero hill of Naples, while on the south the crater is open, with a steep slope which forms the crater wall of the much lower crater basin of Fuorigrotta. The Soccavo basin, whose crater floor is 94 m. in altitude, collects the drainage not only of its own ramparts but also of the Pianura basin by deeply furrowed streams which converge in the torrent of Fosso l'Arena with exit to Fuorigrotta and thence to the sea. The walls of all the three craters of the Camaldoli group, as among the oldest of the region, have suffered a good deal from denudation, but are yet sufficiently defined to establish their origin, outlines, and their relations to each other and the other groups.

## 2. *The Agnano-Astroni Group.*

This remarkable cluster of five cones and craters comprises, besides the older Agnano basin, four of the most recently formed and therefore best preserved volcanoes of the region, and their peculiar superposition invests them with special interest.

*The Agnano Crater*.—The present elliptic basin, 2 by 1 km., is completely encircled by walls of pumiceous, often pisolithic tuff, 100 to 200 m. in altitude, except in the south wall, where the Mte. Spina spur (170 m.) of pipernoid, scoriaceous trachyte projects into it. The crater floor, a former lake, 20 m. above sea-level, was artificially drained in 1870 by a tunnel and an exit canal which discharges into Pozzuoli Bay at Bagnoli. The basin, traversed by the road from Bagnoli to Astroni and Pianura, is well known for its hot springs and carbonic acid exhalations from 30 to 70 and 90 degrees C., notably those of the "stufe di S. Germano" and the hackneyed "Grotto del cane", the last-named fortunately no longer used for exhibiting the gaseous effects on dogs.

The present Agnano crater is only the inner, eccentric crater of the original outer, much larger Archiagnano crater, whose almost circular rim was 4 km. in diameter, i.e. double the area of the inner one. Its western segment occupied the site of the present Solfatara and Astroni craters, which are built up on its ruins, as will appear later. Its northern, eastern (the S. Domenico ridge), and southern segments, within which lies the inner crater, impinge upon the walls of the Pianura, Soccavo, and Fuorigrotta craters, all three of which are therefore older than the Agnano group.

*The Astroni Cone*.—This, the central volcano of the group, and next to Camaldoli the most important of the region, is composed of a perfectly preserved outer ring, elliptic, almost circular in form, 2 km. wide, with a densely wooded crater basin more than 200 m.

deep, from whose floor, barely 14 m. above sea-level, rises the inner, practically concentric cone and crater dell' Imperatrice, a complete atrio or corridor being thus formed between the two. From the outer ring project on the south-west, and opposite on the north-east, midway of the circle, two stump-like old spurs of compact tuff, Torre Nocera and Torre Lupara, 250 m. and 240 m. in altitude, which are the western remains of the original Archiagnano cone. The Imperatrice or inner cone, entirely composed, like the outer one, of pumiceous tuff and detritic material, is of oblong form, 700 m. long, 400 m. broad, and 60 m. in height above the Astroni crater floor. It is breached on the east and there blocked by a lava flow which, welling up from the Astroni crater, formed the two mounds of Rotondella and Pagliaroni, the former a homogeneous, the other, contiguous one a scoriaceous trachytic lava. The whole floor, 1 km. in length and 50 m. high, expands at the end to 200 m. in width, where it partly encircles a small, half-overgrown lakelet as the lowest point of the Astroni crater. This, and several other trough-like old lake basins in the crater floor or corridor, probably indicate plugged vents.

The only other lava mass of Astroni is the remarkable, almost perpendicular cliff called the Caprara, which emerges from the tuff banks of the eastern crater wall, attains a length of 200 m. and 80 m. in height, and is composed of compact, in part scoriaceous, andesitic pipernoid trachyte, much older than the smaller flow on the crater floor. It forms probably part of the Archiagnano cone, as a welled-up, pasty mass whose vent became plugged. Close investigation of Astroni is much impeded by the dense plantation and vegetation of the whole crater basin, which, being a Royal hunting preserve, is protected by a wall all round the 5 km. circumference of the cone-ring. The Astroni cone, measuring at least 8 km. around its base, overlaps both the Agnano and Pianura craters, and is therefore more recent than either. The yellow tuffs of Astroni are largely derived from deposits of that tuff during the great eruptions of Camaldoli on the trachytic platform of the region blown up and re-deposited by the later eruptions and formation of Astroni.

*The Solfatara* crater basin (the *Forum Vulcani* of the Romans) lies midway between Astroni and Pozzuoli Bay, as a completely closed-in crater, with low walls and flat floor, fairly circular, 500 m. in diameter. Owing to its gas and vapour emanations, i.e. *stufe* and *fumarole* up to 80 degrees C., it has become typical of all similar phenomena not only in Italy, but all over the globe. The proximity of the fumaroles to the eastern crater wall, as well as the action of winds blowing in that direction, have completely bleached the hills of that wall; hence their name "Colli Leucogei". The crater walls are built up entirely of pumiceous, in part pisolithic tuff, and only near the Bocca Grande, the principal vapour source, protected by an artificial wall, crops out a pipernoid trachyte vein in various stages of transformation through the action of the hot vapours.

An interesting phenomenon is the old tuff ridge, which links the north crater wall of Solfatara with the Astroni cone at the Torre Nocera spur previously mentioned. Both are remnants and conclusive evidence of the original great Agnano cone, aptly called Archiagnano, on the ruins of whose western segment those two later volcanoes were formed. Solfatara overlaps the present Agnano western crater wall, but is, in its turn, overlapped by the southern flank of Astroni, showing that its age is intermediate between that of the other two volcanoes. It is reputed to have been in eruption in 1198 A.D., but its explosive action could only have been relatively feeble, not productive of much eruptive material, and restricted mainly to unusually high jets of gas and vapour through infiltration from the sea.

*Mte. Olibano and La Starza.*—Closely related to Solfatara are the tuff and trachyte hills along the shore between Pozzuoli and Bagnoli, the names of both these localities being indicative of the hot sulphurous springs in which that shore abounds besides Solfatara. Along the narrow seaboard the Cumana railway tunnels are driven through the old tuff hill of Mte. Dolce (100 m.) and the base of the trachyte mass of Mte. Olibano (100 m.), the former, overlain by marine sand, being the remnant of an old submarine spur ; the latter, largely quarried, resting on marine sand and scoria, and exhibiting marked columnar structure. West of Pozzuoli extends for 2 km. along the shore towards Mte. Nuovo the La Starza cliff or rampart, 60 m. high, of fossiliferous pumiceous tuff, which is either of submarine origin and has been raised, or has been piled up by the sea as a secondary formation.<sup>1</sup>

*Cigliano and Campana.*—Inland to the north, towards Astroni, the Starza cliff continues as a terrace, and adjoins the well-preserved tuff cone and crater of Cigliano, 217 m. in altitude, which is a typical example of a small elliptic, single-vent volcano, not more than 1 km. by 500 m., with a crater over 100 m. in depth. About 2 km. north of it lies the even more interesting, because triple concentric ring volcano Campana, 125 m. in altitude and 500 m. in diameter at its outer ring. Its three cones are composed of the usual pumiceous tuff, ashes, and pozzolana, except the innermost one of Fossa Lupara, in whose wall there is a cleft called La Senga, 2 m. wide and 50 m. deep, which exhibits a vein of trachyte and trachytic scoria. On the north the base of Campana overlaps that of the contiguous ridge of Mte. Viticello, which forms part of the southern wall of the Quarto basin.

<sup>1</sup> The pillars of the temple, market-hall, or, as appears more likely, baths of Serapis at Pozzuoli, which have shared the rise and fall of the coast-line, were, in later Roman times, first embedded to a depth of 3·6 m. in loose tuff ; their base subsequently sank below sea-level ; then, after the Mte. Nuovo eruption, it was raised again, but is still 3 m. below sea-level, the pillars thus not having reached the original level above the surface of the ground ; albeit the coast-line of the Tyrrhenian Sea on the Neapolitan, Roman, and Tuscan shores shows a tendency to rise.

*Sequence of Superposition.*—Both the Cigliano and Campana cones constitute western outliers of Astroni, and as their eastern flanks overlap the base of the latter it follows that they are both of more recent formation than that central volcano of the group, though within the same period of eruption. The order of formation and superposition of the Agnano-Astroni group may thus be summed up as follows : (1) the original Archiagnano volcano ; (2) the inner, present Agnano cone ; (3) Solfatara, formed on the ring of Archiagnano and overlapping Agnano ; (4) Astroni, formed on the same ring, and overlapping Agnano and Solfatara ; (5) Cigliano and Campana outliers, overlapping Astroni. As previously stated, Agnano overlaps on the north the Pianura, on the south-east the Fuorigrotta wall, and is therefore more recent than these two crater basins, though itself the oldest of the Agnano-Astroni group.

### 3. *The Averno Group.*

*Lake Averno Crater.*—This basin of sombre aspect, in Roman times the reputed entrance to the infernal regions, as its name indicates, is in its present attenuated form roughly circular, 1 km. in diameter, with steep walls varying from 80 to 115 m. in height. Its southern wall is formed by the Ginestra ridge (86 m.), its eastern wall is overlapped by the flank of Mte. Nuovo ; the whole ring is composed of pumiceous tuff with ejected blocks of leucite-tephrite, a great many of which are strewn around the crater base. The lake is 35 m. deep, with a flat floor ; in Roman and later historic times the basin abounded in gas and vapour emanations very like those of Solfatara ; but they all disappeared at the time of the eruption of the adjacent Mte. Nuovo. The lake lies practically at sea-level, and served as a refuge port for Roman galleys, for which purpose Agrippa connected it with Lake Lucrino and Baia Bay by a canal, in great part also buried by Mte. Nuovo. A tunnel, i.e. the Grotta della Pace, through Mte. Grillo, the west wall, also connected the lake with Cumae, while the north wall was skirted by the Via Cumana, later surmounted by the aqueduct of Arco Felice, which crosses it at a height of 20 m.

*Mte. Grillo and Mte. Rosso.*—Averno forms, like Agnano, only the inner cone and crater of the originally much larger outer cone of Mte. Grillo (103 m.) and Mte. Rosso (141 m.), the former a crescent-shaped ridge 3 km. in length, enclosing the west wall of Averno and extending north to Mte. Rosso, the last-named ridge running from that point south to join the eastern wall of Averno. These two ridges form immediately north of Averno the walls of the small Scimia crater basin (1 sq. km.), which is probably part of the old crater floor (70 m. altitude) of the original great elliptic Mte. Grillo and Mte. Rosso volcano, 4 by 2 km. This volcano, by analogy with Archiagnano, may, in the present writer's view, be appropriately called Archiaverno.

*Campiglione*.—Contiguous to the northern base of Mte. Rosso rises the low, long, elliptic old tuff ridge of Mte. Ruscello which forms part of the S. Severino basin to be mentioned later. The southwest margin of Mte. Ruscello is overlapped by the flanks of the adjoining, more recent volcano of Campiglione, a finely chiselled elliptic cone  $1\frac{1}{2}$  by 1 km., whose south wall is Mte. Gouro (329 m.) and whose north wall is Mte. Corvara (319 m.). It is composed of pumiceous yellow tuff and débris material, built up on a much denuded floor of older tuff containing marine shells, showing that the floor was formed before the retreat of the sea, while the superposed cone was formed subaerially. The crater floor of Campiglione, completely closed in, is flat and cultivated. The typical single-ring volcano is separated from Cigliano of the Astroni group by a gap through which passes the Via di Campania from Pozzuoli to Mte. Spaccato and Quarto. Mte. Spaccato (70 m. altitude) separates the Quarto basin on the north from the large oblong basin on the south which is surrounded by the Campiglione, Ciglione, and Campana cones. Campiglione is in age intermediate between Agnano and Astroni.

*Cuma*.—On the Tyrrhenian coast, at the western base of Mte. Grillo, lies the yellow tuff mound, about 20 m. high with precipitous sides, upon which stood the ancient city and first Hellenic settlement of Cumæ.<sup>1</sup> At its northern end it terminates in the much higher bluff of the Acropolis (80 m.) composed of the same greyish-yellow tuff with a large subjacent mass of tabular, piperoid trachyte, which, like that of Camaldoli, is overlain by breccia and is exposed towards the sea. The compact yellow tuff yielded the enormous blocks of the city walls; the trachyte, in slabs 2 m. in length, supplied the material for the fortifications. The Cuma mound is an outlier of the Mte. Grillo-Averno group.

*Mte. Nuovo*.<sup>2</sup>—This famous, most recent volcano of the Averno group was formed suddenly in an otherwise quiescent area on 30th September, 1538, amid violently explosive and atmospheric phenomena with dense showers of ashes falling in the city of Naples. On its site, close to the beach of Pozzuoli Bay, stood the hamlet of Tripergole with hot springs used for baths. The eruption buried not only that hamlet, but part of Lago Lucrino and the ancient Roman canal connecting it with Lake Averno, since then replaced by a parallel outlet. The truncated cone is composed of ashes and other loose exploded and pulverized material, older ejected tuffs and scoria, with a small scoriaceous lava flow of piperoid phonolitic trachyte on the south flank of the cone. It is roughly circular around its base and more elliptic in its cone-ring, the former 1 km. in diameter, the latter 370 by 280 m. in major and minor axis. On the

<sup>1</sup> The ancient city of Cumæ was the cradle of Greek colonization of the Neapolitan littoral, Pozzuoli, Baia, and Naples being colonized from there in succession.

<sup>2</sup> The designation Mte. Nuovo is of later date than the cone itself; its original name was Mte. di Cenere, i.e. the mountain of ashes.

western side it rises to 90 m., on the eastern side to 140 m., above the sea, the latter greater elevation being due to the wind having driven the ejecta in that direction. The north-western flank of the cone considerably overlaps the eastern wall of Lake Averno, though it left intact the Apollo temple or baths on the bank of the lake. The flat floor of the deep, funnel-shaped crater is barely 12 m. above sea-level. About 1 km. west of Mte. Nuovo, near the end of Lago Lucrino, rise the hot springs called the "stufe" or "bagni di Nerone", while in the neighbouring tunnel of the Cumana railway which passes under the temple of Diana, similar hot springs of 80 to 90 degrees C. were encountered and greatly impeded the works of construction. The quantity of material piled up by the explosive eruption of Mte. Nuovo, as it were in one night, is computed at 39 million cubic metres.<sup>1</sup>

*Sequence of Superposition.*--In the Averno group this may be recapitulated as follows: (1) the original Archiaverno crater (Mte. Spina, Grillo, and Rosso); (2) the present Lake Averno crater, formed eccentrically in and at the southern end of Archiaverno; (3) the Campiglione cone, overlapping Mte. Ruscello; and (4) Mte. Nuovo, overlapping the wall of Lake Averno.

#### 4. *The Posillipo and S. Severino Basins.*

*The Posillipo ridge*, forming the south-eastern flank of the region, runs from the Vomero hill of Naples south-west to Cape Posillipo and Cape Coroglio, 5 km. in length and 1 to 2 km. in width, the level crest being 140 m. in altitude. Except a superficial mantle of pozzolana tuff, it is composed entirely of the yellow tuff of Camaldoli and Naples with veins and dykes of pipernoid trachyte such as were met with at its base in the road and railway tunnels by which it is traversed. Its eastern versant may possibly be the original wall of a great crater subsided in the Bay of Naples; its western versant forms the wall of the Fuorigrotta basin, which, broad, flat, and almost at sea-level, is bordered on the north by the deeply furrowed slopes leading up to Soccavo, while on the south, towards Bagnoli, it is open to the sea. Its western base is overlapped by the wall of the Agnano crater, and it is therefore older than the latter.

*Mte. S. Severino and Mte. Ruscello* form, together with the Spinelli ridge (112 m.) superposed on the Quarto basin as previously stated, the peripheral crater basin at the north-west end of the region, analogous to the Posillipo-Fuorigrotta basin at the south-east end,

<sup>1</sup> G. de Lorenzo and C. Riva, "Considerazioni sull' origine superficiale dei Vulcani": R. Acc. Napoli, 1902, No. 7. From that volume of the Mte. Nuovo cone, considered as a solid, less the volume of the crater, de Lorenzo has calculated the depth of the cylindrical chimney of 100 m. radius;  $d = \frac{V}{\pi r^2} = 1,248$  m. Considering, however, that the ejecta consist entirely of igneous material without any material of the sedimentary subjacent formations, the actual depth is probably not more than 500 to 1,000 m. The same may apply to all the other cones of the Phlegraean Fields.

Mte. S. Severino is a narrow old tuff ridge 5 km. in length and barely 70 m. in altitude. Mte. Ruscello is more elliptic, 3 by 2 km. at its base and 138 km. in altitude. It has been represented as an isolated ridge resting on some older, demolished volcano, of which there is, however, no trace. Much more probably it and Mte. S. Severino form the two roughly parallel walls of a crater of an early period of eruption.

The foregoing detailed survey of the various crater groups and their sequence of superposition evidenced by their overlapping shows that after the in part submarine formation of the great original semi-circular crater basin of the Phlegræan Fields, bounded by the peripheral walls of the S. Severino, Quarto, Camaldoli, Soccavo, and Posillipo during a first period of eruption, the inner groups were formed by a gradual shifting of the explosive axis: (1) east to west from the Fuorigrotta crater to the Agnano and Averno groups with their outliers; (2) west to east from Campiglione to the Astroni cluster, and, as the most recent phase of explosive activity, again east to west from Astroni to Mte. Nuovo. To these successive displacements of the eruptive axis through the plugging and extinction of previous vents, correspond the three main periods of eruption which, with their component phases, will be recapitulated in the concluding part of this paper.

## V. THE PRODUCTS OF ERUPTION.

The sequence established by the physiographic features of the region is confirmed by the general order of superposition of the products of eruption, to be briefly considered in the following pages. The leading petrographic characteristics will be given in more detail in the Note appended to this paper.

### 1. *The Tuffs.*

The tuffs which, as previously stated, constitute the explosive products and bulk of the Phlegræan Fields, are in ascending order the grey or Campania, the yellow, and the brownish pozzolana tuffs. The first of these are the products of the earliest eruptions in the trachytic platform of the great semicircular Phlegræan crater; the second were supplied by the great Camaldoli crater and, as re-explored and re-deposited material, appear in several of the more recent volcanoes. The same applies to the third, pozzolana tuff.

(1) *The Grey Campania Tuff.*—This trachytic breccia, distributed to a depth of 50 m. or more throughout both the eastern and western Campania and even beyond in many of the Apennine valleys debouching into that plain, contains numerous lapilli, pumice stones, scoria, and ejected trachyte blocks, is fairly compact, loosely stratified, and has been extensively quarried for building and other purposes throughout the Campania ever since Roman times. In the

Phlegræan Fields it constitutes the lowest tuff banks and notably overlies the piperno trachyte of Camaldoli, to which it is closely related as belonging to the same early period of eruption. It is to this period that the vast distribution of this tuff throughout the Campania must be ascribed ; but, having regard to the enormous quantities of ejecta, the eruption was probably not only a local one of the Camaldoli-Pianura crater, but of the whole original crater of the Phlegræan semicircle still partially submerged, before the later inner volcanic groups were built up subaerially on a platform of trachyte and trachytic tuff.

(2) *The Yellow Tuff.*—This well-known “tufo giallo” is, like the older grey tuff, essentially trachytic, but quite distinct from the same by its characteristic and uniform colour, due to its more alkaline and less ferrous composition. Its unstratified banks form the great expanding flank or cone slope of Camaldoli in and around Naples. In the crater wall it overlies the grey breccia ; it also constitutes the extension of the Naples hills, i.e. the Vomero Hill and the Posillipo ridge, and is largely in evidence also in all the Phlegræan islands. In the Phlegræan Fields it further occurs, though in a less bulky form, in the Agnano, Astroni, and Spaccato crater walls, in the terrace from the Starza cliff to Cigliano, and in the southern wall of the Campiglione cone. The yellow tuff is studded with pumice stones, lapilli, and obsidian, and also contains small and large ejected blocks of trachyte. Owing to its general compactness and durability, it is extensively quarried in different parts of Naples, Vomero, and the Posillipo ridges as convenient building material. The railway tunnels and grottos under the Posillipo ridge are driven mainly through this yellow tuff, which here attains a depth of over 100 m. Both in the Naples hills and in the Posillipo ridge trachyte veins and dykes occur in this tuff, as will appear in the sequel. Its principal eruptions must have taken place in that, the eastern part of the region, from the Camaldoli cone, in whose crater cliff it attains 100 m. in depth. In the western part it forms barely a marginal fringe, all the rest of the formerly much larger deposits having been removed by denudation and torrential erosion. A peculiar feature of the yellow tuff is its frequent pisolithic structure, i.e. of pea-like globules formed by raindrops covered with and solidified by pumice.

(3) *The Upper Grey, Pozzolana Tuff.*—This uppermost, essentially pumiceous tuff, known as “tufo bigio”, of greyish-brown colour, overlies the grey and yellow tufts like an ash mantle of more or less loose material several metres in depth, notably on the Camaldoli and Posillipo hills. It forms a similar superficial layer in the central parts of the region, e.g. in the Agnano, Astroni, Campana, Cigliano, Averno, Solfatara, Mte. Olibano, Starza, and Cuma cones and craters. Owing to its well-known property of making excellent cement the pozzolana tuff is extensively quarried and exported, more especially from Baia and Pozzuoli.

2. *The Trachytic Lavae.*

Compared with the enormous masses of tuff, lava flows are in the Phlegræan Fields much less in evidence than in other volcanic regions; they are, moreover, essentially trachytic of relatively low basicity determined by the constant presence of sodalite<sup>1</sup> as conclusive evidence of the magma being affected by infiltrations of, and long contact with, sea-water. This fact warrants the inference that the lavas throughout the region are all derived from the same magma, which underwent little change during the successive periods of eruption. They are probably the result of the uniform trachytic submarine substratum having been re-fused to a fluid or pasty state and re-consolidated during or after eruption.

The oldest and largest trachytic mass of the Phlegræan Fields is that of the Camaldoli and Soccavo crater wall. It is the much debated piperno, alternately reputed to be tuff or lava and vice versa, but indubitably an effusive, homogeneous, and holocrystalline basic rock of 54 per cent silica. It is pale to dark grey in colour, hard, porous, compact, and characterized by conspicuous so-called entaxitic, i.e. fluidal or "Schlieren", also known as "flame", structure due to banded mineral segregations having crystallized on the surface of the rock more slowly than the rock itself. The essential constituents of piperno are augite, sanidine, and sodalite, with plagioclase as subordinate, and biotite, apatite, magnetite, etc., and even hauyne as adventitious minerals. In the Camaldoli crater cliff, nearly 300 m. in height above the floor of the Pianura basin, the piperno mass is deep-seated, rises to 100 m. above the floor, and passes upwards to the lower grey tuff of the same composition, as previously stated.

The principal other, though much smaller, lava flows of homogeneous or scoriaceous trachyte are the numerous dykes and veins in the yellow tuff of Naples, Vomero, and Posillipo, the mass of Mte. Olibano<sup>2</sup> on the south side of Solfatara; the veins in the Solfatara itself, in the Senga cleft of Fossa Lupara, and in the innermost cone-ring of Campana; the mass of the Cuma Acropolis<sup>2</sup> hill at the south end of Lake Licola; the two small flows of Rotondella and Pagliaroni in the Astroni crater, and lastly the remarkable andesitic trachyte cliff of Caprara<sup>2</sup> in the east wall of the same crater, much older than the two small flows on the crater floor, and probably a remnant of the original Archiagnano crater. Besides these, scoriaceous trachytic lava crops out in Mte. Spaccato, Mte. Nuovo, and also constitutes the Mte. Spina spur<sup>2</sup> of the Agnano

<sup>1</sup> Sodalite is as constant and characteristic a constituent of the Phlegræan lavas and tuffs as hauyne is in those of Mte. Vulture.

<sup>2</sup> The trachytic masses of Mte. Olibano, Cuma, Caprara, and Mte. Spina are all the result of slowly welling-up, pasty lava piled up around and over the vent which became plugged. They correspond to the cupoliform lava masses of Melfi in the Mte. Vulture, and of S. Croce in the Roccamonfina group.

basin. The prevalent piperoid structure and the mineralogical composition of the trachyte, with sodalite as constant and characteristic accessory, are substantially the same in all the lava flows, dykes, and veins with 55 per cent silica, except the Caprara andesitic lava with 58 per cent, as is shown in the Petrographic Note. The uniformity of these sodalitic lavas strengthens the inference that the magma from which they consolidated was itself the re-fused product of the great trachytic substratum sodalized by the action of sea-water, and that the seat of that re-fusion was at no great depth below the surface.

Among the characteristic exposures of the products and sequence of eruptions the following are specially instructive :—

(1) *The Camaldoli Crater Wall* (in descending order) :—

25 m. grey-brown pozzolana tuff (bigio) with pumice stones and trachytic fragments ;

100 m. yellow tuff (giallo), with ejected trachyte blocks ;

25 m. bank of varicoloured breccia with ejected blocks ;

25 m. bank of ditto, with ejected slabs and blocks ;

50 m. grey Campania piperoid trachytic tuff ;

100 m. piperno, sodalitic trachyte.

(2) *Astroni Cone* (in descending order) :—

Banks of yellow, compact tuff, with black lapilli and yellow and white pumice ;

Greyish yellow tuff, pumiceous, pisolithic ;

Grey compact and scoriaceous tuff, with lapilli, pumice, and trachytic fragments ;

Trachytic lavas of Caprara, Rotondella, and Pagliaroni in crater.

## VI. CONCLUSION.

As has been shown, of the sixteen more or less well preserved and defined volcanoes of the Phlegræan Fields within the area of the great semicircle, only three, i.e. Archiagnano and Agnano, Archiaverno and Averno, and Astroni-Imperatrice are double-ringed, while Campana is triple-ringed, and all the others, including even Camaldoli, are single-ringed cones and craters. The eruptive activity began towards the end of the Pliocene period with violent, partly submarine, partly subaerial explosions in the great semicircular basin, within which the peripheral and inner groups of volcanoes were formed, in the main subaerially, during the second and third periods of eruption. In the course of these periods, the eruptive axis shifted gradually north-west to south-east, then east to west, then west to north-west, and thence again to east, with a last shifting phase to Mte. Nuovo in historic times.

As was stated at the outset, the violent, but brief eruption of Mte. Nuovo supplies the key to the history of most of the Phlegræan

volcanoes. Exceptions to this rule are the two most important volcanoes of the region, i.e. Camaldoli and Astroni, which were built up by repeated eruptions. There is no reason to assume that the Phlegræan Fields are the oldest volcanic region of the great Neapolitan area; they cannot certainly be older than Mte. Somma, Roccamontefina, Mte. Vulture, or Epomeo of Ischia. Like all these, they were intermittently active throughout the Quaternary period. Thanks to the formation of Mte. Nuovo they share with Vesuvius and Epomeo the privilege of eruptive activity down to and in historic times.

In the present writer's view, the vulcanological history of the Phlegræan Fields may be summarized as follows:—

*I Period.*—Pliocene—Quaternary. General raising of submarine trachytic platform; formation on that platform of great semi-circular low crater wall S. Severino-Camaldoli-Posillipo; great eruption in that crater, partly subaqueous, partly subaerial, of grey Campania tuff with piperno lava mass of Camaldoli, and overlying breccia conglomerates.

*II Period.*—Early and Middle Quaternary. Mainly subaerial.

*1st Phase.*—Formation of peripheral craters Quarto, Pianura, and Soccavo, with S. Severino-Ruscello at western, and Posillipo-Fuorigrotta craters at eastern end. Great eruption of yellow tuff from Camaldoli-Pianura crater; formation of yellow tuff hills of Naples, Vomero, and Posillipo with trachytic dykes and veins. Large deposits of yellow tuff ex Camaldoli in central, southern, and western parts of region, later blown up and re-deposited as part of more recent volcanoes. Yellow tuff banks of Mte. Dolce and Cuma of the same Camaldoli origin.

*2nd Phase.*—Formation of Archiagnano and Agnano with piperno trachyte masses of Mte. Spina and Caprara; Solfatara with trachyte mass of Mte. Olibano; Archiaverno (Mte. Spina, Grillo, and Rosso) and Averno. Campiglione, trachyte boss of Cuma.

*III Period.*—Later Quaternary. Subaerial.

*1st Phase.*—Eruption of brown pozzolana tuff from Camaldoli-Pianura crater, forming mantle over whole region. Formation of Astroni, Cigliano, and Campana tuff cones, mainly by blowing up and re-formation of previous deposits of grey, yellow, and pozzolana tuffs. Similar formation of inner Astroni (Imperatrice) cone with trachytic lava flows Rotondella and Pagliaroni.

*2nd Phase.*—Formation of Mte. Nuovo, A.D. 1538.

It is seen that after the great eruption of the grey Campania tuff as the earliest period, the period of maximum and most prolonged eruptive activity was the second, i.e. of the yellow tuff, while the third period, i.e. of the pozzolana tuff, declined in intensity and became still more attenuated by the sporadic peripheral eruption of Mte. Nuovo as its most recent phase.

## VII. PETROGRAPHIC NOTE AND TABLES.

I. *Sodalite-Trachytes*.—1. *Camaldoli Piperno*, quarried at Pianura and Soccavo partly underground. Pale to dark grey, hard, compact, finely granular porous holocrystalline, with vitreous base. Dominant minerals augite and sanidine in large phenos, with sodalite (often as sublimates of lucent crystals), some plagioclase, biotite, hornblende, nepheline, occasionally hauyne, and magnetite. Pipernoid structure characterized by "flames", i.e. allungated, tapered and pointed segregations of micro-felspar and augite, horizontally grouped on surface of rock constituting entaxitic, fluidal, or Schlieren bands due to slower crystallization than the minerals of the rock itself. Similar structure in "sperone" lava of Lazio and in compact reperino tuff of Viterbo. Similar piperno trachyte in the two great veins, 380 and 110 m. in thickness, in the yellow tuff of Rione Amadeo tunnel (Naples) of Cumana railway; also in Vomero, Posillipo, and, as scoriaceous, phonolitic lava, in the Mte. Nuovo crater.  $\text{SiO}_2$  54 per cent.

2. *Astroni Piperno*.—Similar in composition and structure to Camaldoli; the Caprara type contains more plagioclase, and also leucite; it is an andesitic rather than trachytic lava, i.e. a medium vulsinite. The Rotondella trachyte is similar, only violet and yellow (altered) rather than grey in colour. The Plagiaroni trachyte is the same, but scoriaceous.  $\text{SiO}_2$  58 per cent.

3. *Mte. Olibano, Solfatara, Campana (Senga), Cuma, and Mte. Spina Piperno*.—All these trachytes are similar to Camaldoli, only varying in colour from pale to dark and reddish grey. The trachyte of Mte. Spina contains small quartz crystals in geodes. All the trachytes are more or less rich in sodalite. Mean percentage of  $\text{SiO}_2$  56 per cent.

II. *Ejected Trachytic Blocks*.—Loose or embedded in tuffs, trachyte, trachybasalt, and leucite-tephrite, grey to brown and yellowish, porphyritic to aphanitic; groundmass and segregations of sanidine, augite, with plagioclase, hornblende, olivine, leucite, magnetite, apatite; sodalite always present, also in geodes as sublimate.  $\text{SiO}_2$  55 per cent.

III. *Scoria*.—Generally black, hard, compact, with hard nucleus passing to scoriaceous crust, generally trachytic, rich in enclosures of sanidine, augite, and sodalite with the other adventitious minerals of lava.  $\text{SiO}_2$  57 per cent.

IV. *Breccia*.—Great banks of varicoloured, so-called "Museum" breccia overlying Camaldoli piperno; a pumiceous conglomerate of trachytic, tephritic fragments with sodalite, leucite, and other mineral enclosures.

Tuffs.—(1) Grey Campania tuff, overlying Camaldoli piperno and breccia; scoriaceous and pumiceous, compact mass of ash with trachytic fragments. (2) Yellow tuff, fairly compact, with sanidine, sodalite, and other mineral fragments; often pisolithic. (3) Pozzolana tuff, ashy brown, loose, spongy mass with pumice stones, mineral and vitreous segregations.  $\text{SiO}_2$  of the three tuffs 52 per cent.

TABLE OF MINERAL COMPOSITION OF THE PRODUCTS OF ERUPTION OF THE PHLEGRÆAN FIELD  
 e = essential.      s = subordinate.      a = accessory.

	SiO <sub>2</sub> p.c.	Sandine.	Plagioclase.	Augite.	Sodalite	Magnetite.	Adventitious Minerals.
I. <i>Pipernoid Sodalite-Trachytes.</i>							
Camaldoli, Naples, Pozillipo . . .	54	e	s	e	e	s	biotite.
Astroni-Caprara, andesitic . . .	58	e	e	e	e	s	hornblende.
Astroni-Rotondella and Pagliaroni . . .	56	e	s	e	e	s	olivine (in ejecta blocks)
Olibano, Spina, Cuma	55	e	s	e	e	s	magnetite.
Solfatara, Campana, Mte. Nuovo }							leucite (in ejecta blocks).
II. <i>Ejected Blocks.</i>							nepheline.
Trachytic, trachybasaltic, tephritic	54	e	a	e	e	s	hauyne (Camalde piperno).
III. <i>Scoria</i> . . . . .	57	e	s	e	e	s	apatite.
IV. <i>Breccia Conglomerate, and Tufts, grey, yellow, and pozzolana</i> . . . . .	52	e	a	e	e	s	obsidian.
							quartz (Mte. Spin trachyte in geodes)

## CHEMICAL COMPOSITION.

The following is a typical analysis of the Pipernoid Trachytes of the Phlegræan Fields, as represented by the Astroni group. In the Pipernoid Trachytes is also included that of Mte. Santo (St. Elmo) in Naples, which is closely related to the somewhat more basic trachyte of Camaldoli.

Piperno-Trachyte.	Astroni Group. <sup>1</sup>	Mte. Santo	
		Per cent.	(St. Elmo, Naples). <sup>2</sup> Per cent.
SiO <sub>2</sub> . . . . .	57.58	57.91	
Al <sub>2</sub> O <sub>3</sub> . . . . .	19.39	15.79	
FeO and Fe <sub>2</sub> O <sub>3</sub> . . . . .	4.84	6.82	
MgO . . . . .	1.17	1.66	
CaO . . . . .	4.08	2.99	
Na <sub>2</sub> O . . . . .	3.12	6.01	
K <sub>2</sub> O . . . . .	8.68	7.27	
TiO <sub>2</sub> . . . . .	0.31	0.65	
P <sub>2</sub> O <sub>5</sub> . . . . .	0.21	0.60	
Cl . . . . .	0.17	0.60	
Loss by ignition . . . . .	0.94	0.34	
	100.49	100.27	

<sup>1</sup> G. de Lorenzo, op. cit.<sup>2</sup> Johnston-Lavis, *Geol. Mag.* 1889.

## VII.

### The Phlegræan Islands.

#### I. INTRODUCTORY.

#### II. INNER GROUP.

#### III. OUTER GROUP.

Sketch-maps, Fig. 11 (Paper VI) and Fig. 12 (Paper VIII).

#### I. INTRODUCTORY.

IN the preceding paper it was stated that the Phlegræan Fields and Islands constitute together a continuous volcanic area collectively known as the Phlegræan region. Of this, the Bay of Pozzuoli, with the promontory of Mte. di Procida and the island of Miseno on the west, and that of Nisida on the east, covers about one-third, or 50 sq. km. Outside that bay lies the island group of Procida, Vivara, and Ischia, which really forms part of the Bay of Naples, but by volcanic affinity is an integral part of the Phlegræan region. The aggregate island area is thus 100 sq. km., equal to that of the Fields on the mainland.

The volcanoes of the inner and outer island groups closely resemble each other both in origin and in their products of eruption, more especially as regards the characteristically predominant yellow sodalitic tuff, very similar to that of Camaldoli, Naples, Posillipo, etc., of the Phlegræan Fields. Yet each island exhibits distinctive features of its own.

#### II. THE INNER GROUP (BAY OF POZZUOLI).

1. *The Promontory of Mte. di Procida and Mte. Salvaticchi, Miseno, and Nisida.*—The promontory is linked to the mainland, south of Lake Averno, by a narrow, formerly submerged neck or ridge, barely half a km. wide, which separates the inlet of Baia in Pozzuoli Bay from Lake Fusaro, a shallow lagoon on the Tyrrhenian coast. The neck, over which passes the coastal road from Baia to Cuma near the temple of Diana, is pierced by the tunnel of the Cumana railway, whose terminus is at Torre Gaveta, a bluff close to the sea at the northern base of Mte. di Procida. From the neck southward extend the two ridges of Mte. Salvaticchi (127 m.) and Mte. di Procida (133 to 145 m.) down to Bacoli and Mare Morto respectively, with an eroded depression between them. On the side of the sea Mte. di Procida falls by steep cliffs which at the north end adjoin the tuff boss of Torre Gaveta, pierced by an old Roman exit channel of Lake Fusaro. The two ridges, about the same elevation, obviously formed originally one dome-shaped isolated ash hill, probably piled up during an eruption in the neighbouring island of Procida.<sup>1</sup>

<sup>1</sup> Strabo regarded the island of Procida as a fragment of Ischia, detached from the latter by a submarine or terrestrial convulsion.

On the south and east, the base of Mte. Salvaticchi adjoins, and is in part overlapped by the more recent chain of small cones and craters, worn by the scouring of the sea, of Cape Miseno, the well-known conspicuous, flattened cone of perfect outline, Porto Miseno, Bacoli, and the crater basin of Baia. Among these are specially notable the two twin cones and craters, now overgrown with vine, of Fondi di Baia, on the height between Bacoli and Baia, these craters having, according to Scacchi, been formed as recently as 1850. The small island of Nisida, 5 km. distant from Miseno at the opposite or Posillipo end of Pozzuoli Bay, is a low circular cone whose crater is breached and washed out on the south-west.

All these volcanic hills are built up of banks and walls of more or less compact yellow tuff overlain by a thin mantle of earthy pozzolana tuff with intermediate layers of pumice and scoria, pointing to repeated accumulations of volcanic material. The only evidence of lava consists in a flow or mass of black scoriaceous trachyte which crops out at the not very accessible south-west base of Mte. di Procida at Punta di Fumo, and also in the neighbouring reef or scoglio di S. Martino. The cliff at the north end of Mte. di Procida, near Torre Gaveta, exhibits banks of variegated breccia, like that of Camaldoli, with fragments of trachyte, pumice, red scoriaceous tuff and bombs, zeolites, and, at the base of the cliff, marine fossils washed in by the sea. The promontory and Miseno are easily accessible from Baia, whence the picturesque littoral road, after crossing the neck, runs along the depression between the two ridges to Mare Morto and Miseno, and thence to Bacoli and back to Baia.

### III. THE OUTER GROUP (PROCIDA AND VIVÀRA).

*Procida*, the ancient Prochyta, 5 km. south-west from the Mte. di Procida promontory, is an island not more than 75 m. in altitude at the highest point of the ridge which forms the eastern shore, whence it slopes down to the flat western shore. Its area is 4 km. in length, and 1 km. in width. The two semi-elliptic bays of Procida and Centano on the east coast are clearly segments of former craters subsided or washed out by the sea. The castle of Procida at the north-eastern extremity of the island is built on a spur forming the north point of the bay of that name. The base of the rock exhibits a mass of grey trachyte, in which dark obsidian strikingly contrasts with white lucent sanidine crystals. The north of the island is remarkable on account of a trachytic lava flow up to 2 m. in thickness at Punta di Riccioli, overlain by breccia and pumiceous tuff. The breccia contains blocks of sanidinic, leucitic, and augitic lava, while the tuff is fossiliferous, and both are overlain by yellow tuff, the whole exposure being thus a replica of that of Mte. di Procida. For the rest, the island is composed of yellow tuff, and as such closely related to the promontory of that name. The yellow tuff is well exposed in the south-western tongue of the island, at

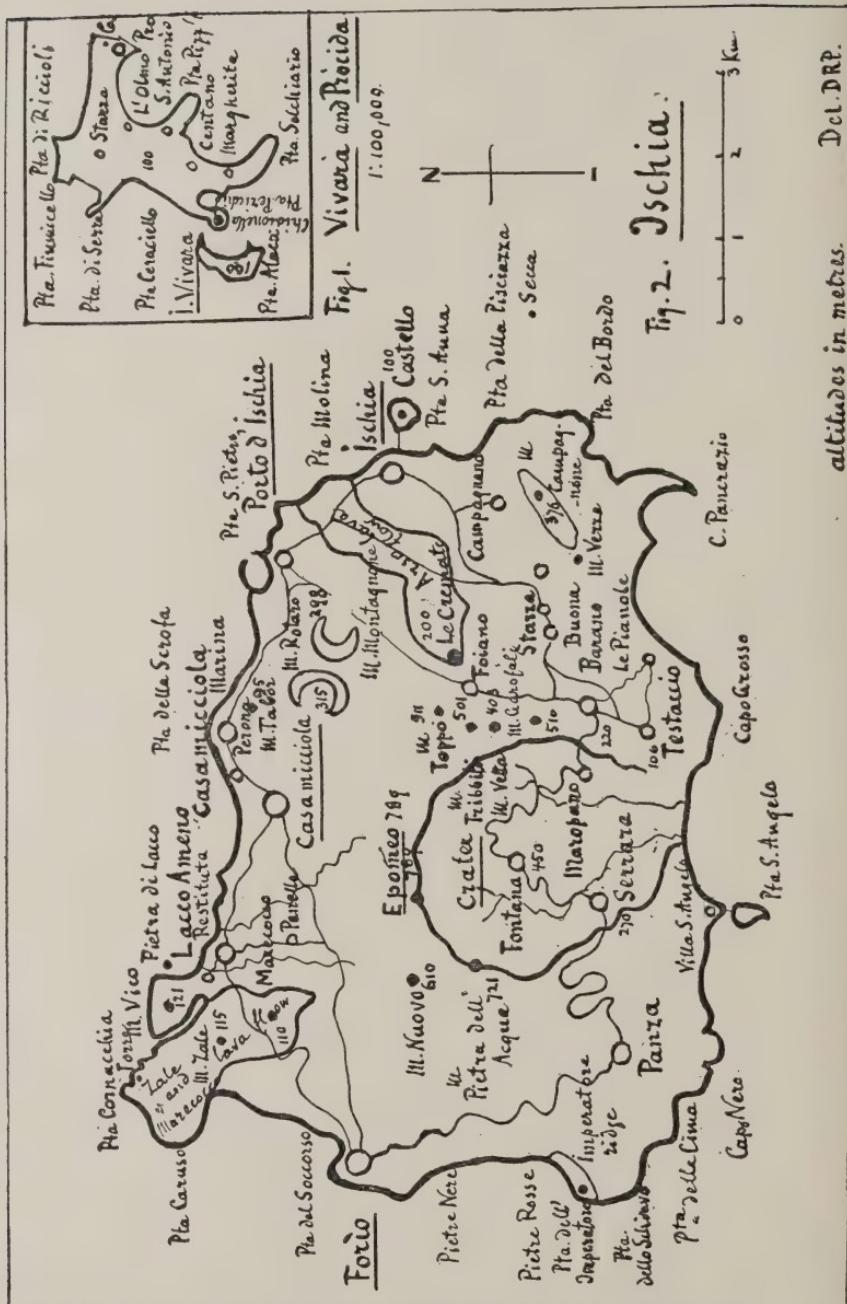
Punta Margherita, midway of the segment of the Centano cone, opposite Vivara.

Vivara, within half a km. of the south-west point of Procida and formerly connected with the latter, is the remaining crescentic segment of a submerged crater 1 km. in diameter in the circular bay of Cenito between the two islands. In Vivara the crescentic steep-walled cone ring is formed by a ridge 100 m. in altitude at its highest point; in Procida the cone is marked by the bluff called Punta del Perrichio. The now submerged crater has evidently been the scene of violently explosive eruptions without lava flows, but with large quantities of ejecta, among them blocks and fragmentary material not only of trachyte, but of basalt and even of older, dioritic rock, quite an exceptional phenomenon in the whole Phlegræan region. It is on this account that Vivara, small though it is, almost eclipses its larger neighbour Procida in vulcanological interest.

At Punta Ciraciello, the northern extremity of the island, a spur not more than 10 m. in height discloses a bank of variegated breccia overlain by yellow and then greyish brown tuff, the former with mostly trachytic blocks. Another, larger, and highly instructive exposure, 100 m. in height, is that of Punta Alaca, the extreme southwest point, exhibiting a wall of three successive, superposed banks of breccia with intermediate tuff and pumice banks.<sup>1</sup> These breccia banks contain a remarkable variety of fragments and blocks of lava: e.g. the lowest and middle banks dioritic rock, plagioclastic and scoriaceous basalt, trachytic andesite, sanidine-trachyte, etc., the upper banks micaceous, vitreous, and sodalitic trachyte and piperno, the more basic rocks predominating in the upper, the more acid in the lowest and middle banks. Vivara thus offers valuable evidence of the considerably older igneous substrata from which these fragments and blocks were derived during successive phases of eruption. Of the tuffs particulars are given in the Petrographic Note appended to the paper on Ischia (VIII). The breccias and the overlying grey and yellow tuffs correspond with those of the island of Procida and of Mte. Procida at the point of Pozzuoli Bay. The breccias are probably of submarine origin, the grey tuffs partly submarine, partly subaerial, and the yellow tuff and ejecta subaerial, as is also the superficial pozzolana tuff of Procida. The products of the two islands thus accord strikingly with the sequence of superposition and the three periods of eruption of the Phlegræan Fields.

<sup>1</sup> These sections are described in great crystallo-petrographic detail by de Lorenzo and Riva in their Memoir on Vivara, *Atti Acc. Napoli*, 1902.

Fig. 12.



## VIII.

### Ischia.

- I. INTRODUCTORY.
- II. THE VOLCANOES AND PRODUCTS OF ERUPTION.
- III. CONCLUSION.
- IV. PETROGRAPHIC NOTE AND TABLES.  
SKETCH-MAP, FIG. 12, AND PHOTOGRAPH, FIG. 19.

#### I. INTRODUCTORY.

THE ancient Pithecusa, later Aenaria, and still later, in the ninth century A.D., known as Iscla, lies 5 km. west of Procida, on the periphery of the great volcanic area of the Phlegraean Fields, Vesuvius, and the Bay of Naples comprised in a circle of roughly 25 km. radius. In this area, Ischia enjoys the privilege of being the first volcanic region whose eruptions were authenticated by the ancients. Its earliest records go back to the eighth century B.C., when the first Greek Eretræan and Chalcidian settlers<sup>1</sup> abandoned its fertile soil owing to the terrible earthquakes and eruptions of "fire, sea, and scalding springs". Similar phenomena induced the later Greco-Syracusan settlers to leave it for Cuma about 470 B.C., terrified by the legendary Typhoeus lying below the island and convulsing it with his groanings and the movements of his giant body, as his brother-giant Enceladus was reputed to do below Etna. Further eruptions of Ischian volcanoes are recorded in 350 and 89 B.C., though even these were anterior to the first authenticated eruption of Vesuvius in A.D. 79. Similar volcanic and seismic phenomena are recorded in the first three centuries of the Christian era.<sup>2</sup>

Strabo (60-20 B.C.) and also Pliny (A.D. 23-79), adopting the more enlightened views adumbrated 400 years earlier by Pindar (522-448 B.C.), and the accounts of Timæus of Taormina (352-256 B.C.), regarded the whole Neapolitan coast from Cuma to Sicily as in a permanent state of subterranean ignition in deep-seated chasms communicating with the sea. Among the first modern scientific writers on Ischia were Breislak and Braucci in 1798 and 1837, followed by Abich's even now classic work, and more recently by Fonseca and Fuchs, Roth, dell' Erba, Deecke, and other authors of

<sup>1</sup> Both the Eretræans and the Chalcidians came as pioneer traders from Eubœa and founded settlements on the north-east coast of Ischia. The Syracusan Greeks, sent by Hiero, tyrant of Syracuse (478-467 B.C.), founded a settlement 400 years later on the north-west coast of the island, probably near Forio. Both settlements were destroyed by successive earthquakes and eruptions.

<sup>2</sup> In the reigns of Titus, Antonius Pius, and Diocletian.

partial contributions previously quoted.<sup>1</sup> Of luxuriant fertility, except as regards the more recent lava fields, Ischia possesses in a pre-eminent degree the fatal gift of beauty, for it has at all times been the victim of disastrous earthquakes, the most recent of which, i.e. of Casamicciola in 1883, involving the loss of 1,700 lives, gained for the vine- and pine-clad island the unenviable name of "terra insanguinata".

## II. THE VOLCANOES AND PRODUCTS OF ERUPTION.

1. *Epomeo*.—Ischia constitutes a complete unit of eruptive activity, its only former, now submerged connexion being probably with Vivara, Procida, and Mte. di Procida as a continuous submarine, later subaerial chain of volcanoes. The island forms an irregular rectangle of 8 by 6 km., 25 km. in circumference, in whose approximate centre rises, like a majestic truncated pyramid, Epomeo, its principal volcano, to 792 m. above sea-level. The single-ringed, slightly elliptic cone, 3½ by 3 km., is breached on, and faces the south, thus forming a typical horseshoe whose breach walls extend for about 1 km. right down to the sea, where they end in the headlands of S. Angelo and Cape Grosso with precipitous cliffs 100 to 150 m. high. The highest points of the cone-ring and its flanks, besides Epomeo itself on the north, are Mte. Nuovo and Pietro dell' Acqua (620 and 731 m.) on the west, and Mte. Tribbiti and Mte. Vetta (501 and 511 m.) on the east; from these points the flanks descend to the foothills and undulating fertile littorals of Forio and Ischia respectively. The northern wall of Epomeo falls almost perpendicularly, and its lower flank then slopes down and expands to the foothills of Casamicciola and the north coast. The western and eastern walls are less steep, but still precipitous; the visible base of the walls all round measures about 13 km., or roughly one-half of the total circumference of the island.

The original lower flanks of the volcano, which extend down to the coast, are covered in great part with the explosive products of its own and of later parasitic eruptions. The present island probably represents only the nucleus of the original volcano, and occupies an area about one-half of that of the Phlegræan Fields. The floor of the extremely steep-walled crater of Epomeo has its plugged centre in the site of the village Fontana at 450 m. altitude, the crater being thus no less than 300 m. in depth. On the west and east breach walls and their flanks, south of Fontana, are perched respectively the villages of Serrara (270 m.), Maropano, Barano (220 m.), and

<sup>1</sup> Apart from numerous papers on the hot springs, earthquakes, and the history of Ischia and the Phlegræan Islands, the most notable geological contributions, besides those by Breislak (1798), Braucci (1837), Scacchi (1841–82), and Deecke (1903), already quoted, are: H. Abich, Ischia, 1841; F. Fonseca, Ischia, 1870; C. W. Fuchs, Ischia, 1872; I. Roth, Geologie Neapel, etc., 1882; L. dell' Erba, La Lava d'Arso, 1895; H. S. Washington, Ischian Trachytes, Am. Journ. Geol., 1896.

Testaccio (106 m.), these places and Fontana being linked by a tortuous, alternately rising and falling mountain road, which outside the crater extends on the west to Forio and on the east to Ischia, the two largest towns of the island. The road thus traverses the whole southern part of the island, while on the north the two towns are linked by a road which skirts the foothills and seaboard, connecting the intermediate places of Porto d'Ischia, Casamicciola, and Lacco Ameno. A third road leads from Porto d'Ischia over the great Arso lava field to Barano, and the three roads thus afford convenient access to all the points of geological interest.

The fairly well preserved cone and crater walls of Epomeo are built up mainly of loosely stratified banks of characteristic greenish-yellow pumiceous and sanidinic tuff, crowned on the summit by the former hermitage of S. Nicola. This yellow "Epomeo" tuff, similar to that of the Phlegræan Fields, covers the whole crater, the cone-ring, and the western and northern flanks of the volcano, indeed, of the island, while on the north-east and east it is in great part overlain by the products of later, parasitic eruptions. The crest and walls of Epomeo are bare and rugged; the upper flanks are in part covered with pine plantations, the lower flanks and foothills mainly with vine and orchards. Owing to the absorbent volcanic soil, Epomeo, like the rest of the island, is poor in streams, though its flanks, more especially on the south, are deeply furrowed by gullies. The only streams are one in the crater-breach with an outside affluent descending from Mte. Tribbiti in the south, and two in the north, i.e. one at Casamicciola and another at Lacco.

2. Between the upper and lower flanks of Epomeo on the north, east, and south-east lies a belt of greyish, marly, marine shell-bearing clay, up to about 200 m. altitude, which consists in part of earthy marl, in part of argillaceous marl, and in part of plastic clay, the first being a product of the decomposition of trachytic tuff, the second of trachyte, and the third of that tuff with added carbonate of lime. It is this last-named clay, locally called "creta"—as distinguished from the "marna"—which has from the earliest times been used for making "mattoni", i.e. tiles and pottery characteristic of the island. The kaolinization of the tuff and trachyte is due to the action of salt water, and affords conclusive proof of the belt having been formed during the emersion of Epomeo from the sea in late Pliocene and early Quaternary times.

The crater of Epomeo reveals no trace of lava flows; on the other hand, great superposed alternating banks of trachytic lava and grey tuff extend like a plateau from the south-west margin of the cone down to the sea, covering a tract of 4 km. in width from the precipitous ridge and bluff of Punta dell' Imperatore (237 m.) to Capo Nero and Punta S. Angelo, where they form the cliffs and headlands between these points, including the detached trachytic boss of S. Angelo. Similar trachytic lava flows and tuffs are traceable in the south-eastern and eastern part of the island. They

show that Epomeo emitted from its flanks before and during its emersion extensive lava flows, upon which the cone and its later products of eruption were built up subaerially in Quaternary and historic times. The platform of trachytes and grey tuffs of the southern and south-eastern area of the island thus represents the mainly submarine and therefore oldest volcanic formation; the greenish-yellow Epomeo tuff of the central, northern, and western area represents the early subaerial formation, and the parasitic volcanoes, lava flows, and pumiceous tuffs of the north-eastern and north-western area represent the more recent subaerial, in great part historic formation. The island may thus be described as consisting of three belts of volcanic products, grouped round the central volcano of Epomeo.

3. *The External Cones, Craters, and Lava Flows.*—After the extinction of the Epomeo crater through its explosive vent becoming plugged, the eruptive axis shifted in succession to the eastern and northern periphery of the island, giving rise to the following volcanic formations :—

(1) *The Campagnano Group.*—This constitutes the south-eastern corner of the island and clusters round the large volcano Mte. Campagnano (376 m.), now represented by a trachyte and tuff ridge 1 km. in length. It is built up on the platform of the older trachytic lava and tuff banks previously mentioned, and its flanks extend to the precipitous eastern and southern cliffs and headlands from Punta Pisciazzà to Punta del Bordo, and Punta Pancrazio. Mte. Campagnano is flanked by the trachyte and tuff bosses of Mte. Vezza (236 m.) and Toppo di Campagnano (105 m.), the group having evidently formed a separate centre of eruption. The ridge is probably the north wall of a large, now submerged crater, of which the two trachytic headlands of Punta Pancrazio and Punta del Bordo form the remains of the west and east walls respectively.

(2) *The Tribbiti Group.*—This cluster of volcanic hills superposed on the upper eastern flank of Epomeo comprises the trachyte and tuff masses of Mte. Tribbiti and Garofali (512 m. and 403 m.), Mte. Vetta, and Mte. Toppo<sup>1</sup> (511 m.). The first three, of which Mte. Garofali is the largest, constitute a lava flow from the flank of Epomeo posterior to the explosive eruption of the yellow tuff; Mte. Toppo, entirely composed of pumiceous tuff, dates probably from the same eruption as the lava flow, as it rests on yellow tuff. The whole group is thus a subaerial formation of later date than Epomeo.

(3) *The Ischia Castle Rock*, on the east coast, a detached boss 100 m. high, almost circular, 250 m. in diameter and 100 m. in height, is composed of dark phonolitic trachyte overlain by pumiceous tuff,

<sup>1</sup> "Toppo" is the exact equivalent of "boss", and is commonly used in Southern Italy as denoting a detached hill.

precisely similar to the neighbouring headland of St. Anna, with which it was formerly continuous. The trachyte forms part of a lava flow from Epomeo during the first period.

(4) *The Montagnone Group.*—This north-eastern group forms, like Campagnano in the south-eastern corner, a separate centre of eruption. It comprises (a) the two well-preserved contiguous cones, each about 1 km. around their base, with the typical funnel craters and external lava flows of Montagnone (298 m.) and Mte. Rotaro (315 m.), both built up of trachyte and scoriaceous pumiceous tuff rich in obsidian. The neighbouring boss of Mte. Tabor (95 m.) is a lava flow from Mte. Rotaro, superposed on the northern flank of the latter, midway between it and the coast; (b) the remarkable circular crater of Lago del Bagno, a crater lake which in 1856 was converted into the harbour of Porto d'Ischia, and whose entrance is guarded by two trachyte bosses piled up by that crater.

The successive eruptions of Montagnone and Rotaro, with their lava flows to the coast, and the formation of the crater lake basin of Porto d'Ischia, constituted the catastrophes which in the eighth century B.C. caused the Greek settlers of that early period to leave the island, as recorded by Strabo and Pliny.<sup>1</sup> A later eruption of Mte. Rotaro took place in 350 B.C., as described by Timeo of Taormina,<sup>1</sup> and a still later one in 90 B.C., as recorded by Obsequens.<sup>2</sup> The whole area between the two volcanoes and the sea, about 5 sq. km., is covered with their trachytic scoria. The pumiceous tuff which overlies the old trachytic platform all over the eastern part of the island is the product of their repeated eruptions, mainly in historic times.

(5) *The Marecocco Group.*—This large group forms the north-western corner of the island and comprises:—

(a) The trachytic headland of Mte. Vico (121 m.), close to Lacco Ameno, and the detached boss Pietra del Lacco, locally called "il Fungo", a fungus- or hat-shaped tuff mound near the shore, the remnant of a former, much longer spur.

(b) Mte. Marecocco (110 m.) and Mte. Zale (115 m.), about 1 km. south of Lacco, which together constitute the largest lava flow of the island,  $2\frac{1}{2}$  km. in length and over 1 km. in width, from the north-western flank of Epomeo. Mte. Marecocco forms a ridge, Mte. Zale an enormous adjoining expanse of lava, which constitutes the great headland between Punta Cornacchia, the north-western extremity of the island, and Punta Caruso. The road from Lacco to Forio crosses the lava flow in the depression between the two hills, which, like the whole lava field, are encumbered with chaotic, superficial masses of blocks, scoria and débris, and are only here and there sparsely covered with vegetation. This lava flow marks the great eruption of 470 B.C., which compelled the Greco-Syracusian

<sup>1</sup> Op. cit.

<sup>2</sup> I. Obsequens, Prodigii.

settlers to leave the island, as recorded by Timæus of Taormina and Strabo.<sup>1</sup>

(6) *The Arso Lava Flow.*—This great eruption of 1302, recorded by Pontanus, took place<sup>1</sup> on the eastern flank of Epomeo and represents the most recent shifting of the eruptive axis and the latest historic phase of eruptive activity in the island. The point of eruption lies between Ischia and Mte. Tribbitti, 200 m. above sea-level. Piling up a semicircular wall of scoriaceous lava round the vent, called “Le Cremate”, the Arso lava flow, largely scoriaceous, about 2 km. in length, half a km. in width, and 5 to 15 m. in depth, reached the shore between Ischia and Porto d’Ischia and plunged into the sea, where it formed the trachytic headland of Punta Molina. The vent and adjacent slopes are now clad with pine, but the lava field, which is covered with a chaos of débris, and over which runs lengthways the new road from Porto d’Ischia to Barano, is for the greater part still barren, because highly porous and scoriaceous and, moreover, waterless. Contrary to the Vesuvian tradition of such soil yielding abundant vegetation after 100 years, the Arso lava field is to-day very much what it must have been after the eruption more than 600 years ago.

4. *Earthquakes and Hot Springs.*—From the earliest times Ischia has, as previously stated, been visited by disastrous seismic disturbances. The eruption of 1302 was, within a year, both preceded and followed by severe shocks, and the great earthquake of Casamicciola in 1883, similarly preceded and followed by minor shocks, was therefore justifiably regarded as heralding a fresh volcanic outburst, which contingency has been hanging over the island like a cloud ever since. A seismic observatory was, after 1883, providently established at Ischia for the purpose of giving timely warning. Previous earthquakes, all of them in the region of Casamicciola, i.e. on the northern flanks of Epomeo and near Montagnone and Mte. Rotaro, were experienced in 1828, 1852, and 1867. Since the catastrophe of 1883 the same northern part of the island was, in 1910, visited by a disastrous torrential mud-flow descending from the flanks of Epomeo as the result of a cloudburst, the volcanic mud and débris overwhelming the already ruined slopes and beach of Casamicciola.

The seismic disturbances show that the old volcanic vents are not yet completely plugged, either by the superincumbent weight of accumulated material or by the consolidation of the magma in the chimneys or fissural passages. This is further attested by the numerous hot springs, both saline and sulphurous, for which Ischia, like the littoral of Pozzuoli Bay, has long been famous. They are not only disseminated around the coastal belt, but appear at various points in the sea near the shore. Of the former, which range up to

<sup>1</sup> I. J. Pontanus (Danish historian), *De bello Neapolitano*, Basle, 1538. The Arso eruption of 1302 was also recorded by Marenta in 1559 and by Lombard in 1566.

70 deg. C., the most notable are those on the north coast, e.g. of Bagni d'Ischia, S. Gerolamo, Arsolava, Mte. Tabor, Casamicciola, and Lacco Ameno. The earthquake of 1883 caused a considerable fissure in the northern flank of Epomeo above Casamicciola, from which issued hot vapours—a phenomenon which attests the thermal origin of the catastrophe at no great depth below the surface.

### III. CONCLUSION.

The five Phlegræan Islands, together with the promontory of Mte. di Procida, constitute a continuous volcanic chain 25 km. in length, which forms the northern rampart of the bay of Naples, as the sedimentary ridge of Castellamare and Sorrento (with the island of Capri) does on the south. The breccia banks of Mte. di Procida, of Procida, and of Vivara, overlain by grey tuff, in its turn overlain by yellow tuff covered by a mantle of pozzolana tuff, show that in this region, too, as in the Phlegræan Fields, the volcanic activity comprised three principal periods.

The same sequence is, in the present writer's view, traceable in Ischia, where the three periods are constituted as follows:—

*I Period.*—Late Pliocene and Early Quaternary. Submarine and Subaerial Uprise of old Epomeo lavas and grey trachytic and pumiceous tuffs as nucleus and platform of island. Formation of Creta belt.

*II Period.*—Middle Quaternary. Subaerial. Great explosive eruption of Epomeo crater; formation of yellow tuff cone in centre and of deposits of same tuff around the cone in western, northern, also in eastern part of island. Breach of crater on the south.

*III Period.*—Recent Quaternary and historic. Subaerial.

*1st Phase.*—Eruption and formation of Campagnano group in south-eastern corner of island with trachytic lavas and pumiceous tuffs.

*2nd Phase.*—Eruption on eastern flank of Epomeo; formation of Mte. Tribbiti, Vetta, and Girofali group of lava flows and of Toppo pumiceous tuff.

*3rd Phase.*—Eruptions and formation of Montagnone and Rotaro cones on north coast with lava flows; also Mte. Tabor lava mound ex Rotaro, pumiceous tuff, and scoria deposits near coast, in eighth century B.C.

*4th Phase.*—Eruption on north-western flank of Epomeo; formation of great lava flows of Marecocco, Zela, and Mte. Vico in 470 B.C.

*5th Phase.*—Eruptions of Mte. Rotaro on north-eastern coast; formation of crater lake of Bagno d'Ischia, 350 and 89 B.C.

*6th Phase.*—Eruption on eastern flank of Epomeo; formation of great Arso lava flow in A.D. 1302.

As in the Phlegræan Fields, so also in Ischia, the second period of eruption, i.e. of the Epomeo yellow tuff, was that of maximum explosive activity, while the successive phases of the third period

mark a repeated shifting of the eruptive axis and a still formidable, though less violent, volcanic activity on the periphery. The single-ringed cones and craters of Ischia point to their predominantly explosive character, but the great lava flows from the flanks of Epomeo in historic times, albeit at intervals of 400 to 1,000 years, show that while its explosive crater is apparently extinct, its capacity of effusive eruptions on its flanks is still alive. It is a noteworthy feature that the magma, even in the space of 1,500 years, shows a variation of barely 1 to 3 per cent in silice (*vide Petrographic Note*).

The former continuity of the island chain is, in a measure, confirmed by the volcanic, now submerged reefs or "secche", of which the five principal ones in the bays of Naples and Pozzuoli and on the coast of Ischia lie from 5 to 50 m. below the surface of the sea. As in the Phlegræan Fields, so also in the Islands, and most of all in Ischia, the sequence of eruptions shows a marked tendency to shift from the centre to points of the periphery. Regarding the Neapolitan volcanic area as a whole, the great central crater may originally have been in the bay itself, and the Phlegræan Fields, the Islands, and Somma-Vesuvius may constitute so many peripheral centres of eruption. Among these, the Islands represent in themselves a formidable group, crowned by Epomeo of Ischia which, in its imposing grandeur and the magnitude of its past eruptions, is second only to Vesuvius.

#### IV. PETROGRAPHIC NOTE AND TABLES.

(1) *The Breccias* of Mte. di Procida and the islands of Procida and Vivara are, like those of Camaldoli etc. of the Phlegræan Fields, composed of cemented fragments and blocks of massive igneous rocks, torn from the chimney walls by the magma in its upward passage, and of blocks and lumps of magma consolidated as lava, scoria, pumice, obsidian, etc.

(2) *The Tuffs*, both the old grey trachytic and the yellow (Epomeo, etc.), are compact, densely packed conglomerates of dark resinous, vitreous lapilli, whose size varies from a nut to a pea and pin-head; very porous, cemented by grey or yellow sodalitic-trachytic ash, with enclosures of felspar, augite, biotite, obsidian, and numerous other minerals. The more recent pumiceous tuff of Ischia is largely composed as above, but with a much more considerable, indeed predominating, admixture of pumice fragments and pebbles, held together by pumiceous cement. It is a fine, loose breccia rather than a compact tuff like the grey and yellow. The silica percentage of the three tuffs varies from 53 to 60.

(3) *The Ischian Lavae*.—These all exhibit a vitreous, trachytic groundmass, often with porphyritic structure, the minerals which appear as phenos also appearing as segregations in the groundmass. Two constantly present minerals of the Ischia lavas, besides their dominant constituents of sanidine and augite, are sodalite and obsidian. The old trachyte of Punta dell' Imperatore is compact,

dark brown, with phenos of sanidine. The later trachytes of Mte. Campagnano and Mte. Vezza are pale to dark grey with phenos of sanidine and augite. The Mte. Vetta, Mte. Garofali, and Mte. Tribbiti trachytes are fine-grained, grey, with phenos of sanidine, augite, and sodalite. The trachyte of Montagnano, Rotaro, and Mte. Tabor exhibits a large variety of pale to dark grey sodalitic rock rich in obsidian, with phenos of sanidine and augite, that of Mte. Tabor being notably brick-red in colour, with melilite and with cavities containing sublimates of sodalite, augite, hypersthene, and biotite. The dark phonolitic trachyte of the Ischia castle rock is particularly rich in sodalite. The Mte. Vico, Marecocco, and Zale lavas are pale grey sodalite-trachytes, with phenos of sanidine, augite, biotite, and also hornblende, disseminated in the vitreous groundmass. The Arso lava is a sodalite-olivine-trachyte; grey, porous, with vitreous base in which are disseminated phenos of sanidine and augite, some plagioclase, biotite, and olivine, also enclosures and segregations of sanidine and magnetite. The silica percentage of both the older and more recent trachytes varies from 60 to 63 per cent, the most recent being also the most basic lava, i.e. that of Arso, with 57·73 per cent silica. Its specific gravity is 2·61; that of the other lavas varies from 2·43 to 2·53.

(4) *Ejected Blocks in Breccias and Tuffs of Vivara*.—Diorite, scoriaceous basalt, andesite-trachyte, sanidinite, micaceous, vitreous, and sodalitic trachyte, piperno.

(5) *Mineralogical Composition of the Lavas* :—

*e* = essential.

*s* = subordinate.

*a* = accessory.

	SiO <sub>2</sub> p.c.	Spec. Gravity.	Sanidine.	Plagioclase.	Augite.	Sodalite.	Biotite.	Olivine.	Obsidian.	Magnetite.	Adventitious.
<i>Trachytic Lavas</i> —											
ocida Castle Rock . . .	61·50	2·45	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>	<i>s</i>	—	<i>a</i>	<i>s</i>	hornblende.
<i>Ischia</i> —											
e. Punta dell' Imperatore	61·05	2·53	<i>e</i>	—	<i>e</i>	<i>e</i>	<i>s</i>	—	<i>a</i>	<i>s</i>	hypersthene melilite.
e. Campagnano, Vezza,											
Ischia Castle Rock . . .	63	2·48	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>	<i>a</i>	—	<i>a</i>	<i>s</i>	apatite.
e. Vetta, Garofali,											
Tribbiti . . . .	61·87	2·45	<i>e</i>	—	<i>e</i>	<i>e</i>	<i>a</i>	—	<i>a</i>	<i>s</i>	titanite.
e. Montagnone, Rotaro,											
Tabor (eighth century, 350, and 89 B.C.) . . .	61·73	2·44	<i>e</i>	—	<i>e</i>	<i>e</i>	<i>s</i>	—	<i>a</i>	<i>s</i>	
e. Marecocco, Zale, Vico											
(470 B.C.) . . . .	61·49	2·43	<i>e</i>	—	<i>e</i>	<i>e</i>	<i>a</i>	—	<i>a</i>	<i>s</i>	
so (1302) . . . .	57·73	2·61	<i>e</i>	<i>s</i>	<i>e</i>	<i>e</i>	<i>s</i>	<i>a</i>	<i>a</i>	<i>s</i>	

(6) *Chemical Composition of the Lavas*.—The Ischian lavas contain 4 to 5 per cent more silica than those of the Phlegraean Fields, with the exception of the Arso, i.e. the most recent lava,

which, although highly scoriaceous, varies from 57 per cent in the flow towards the coast, down to 54 per cent in the most scoriaceous lava of "Le Cremate", the lava wall at the upper end. For the rest, all the Ischian lavas reveal essential uniformity of chemical composition, as is shown by the following typical analyses.<sup>1</sup> The lava flows of Marecocco and Arso are the two largest in the island.

	<i>Marecocco. Mte. Tabor.</i>	<i>lava flow.</i>	<i>Le Cremate.</i>	<i>Arso</i>
	Per cent.	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub>	61.49	62.17	57.73	54.83
Al <sub>2</sub> O <sub>3</sub>	20.02	20.83	17.85	20.17
FeO and Fe <sub>2</sub> O <sub>3</sub>	5.63	4.38	8.34	8.63
MgO	0.52	0.45	1.77	1.93
CaO	1.88	1.68	3.65	4.12
Na <sub>2</sub> O	3.39	4.40	3.77	3.05
K <sub>2</sub> O	7.13	6.76	7.65	7.38
P <sub>2</sub> O <sub>5</sub>	0.02	0.03	—	—
Loss by ignition	0.46	0.25	0.09	0.46
	100.95	100.95	100.85	100.56
Sp. gr.	2.43	2.45	2.61	2.74

<sup>1</sup> These analyses (Fuchs, op. cit.) agree substantially with others by Abich vom Rath, and Manasse.

## IX.

### **Somma-Vesuvius.**

- I. INTRODUCTORY.
- II. GENERAL FEATURES.
- III. THE VOLCANIC EDIFICE.
- IV. PREHISTORIC AND HISTORIC ERUPTIONS.
- V. CONCLUSION.
- VI. THE PRODUCTS OF ERUPTION. PETROGRAPHIC NOTE AND TABLES.
- VII. LIST OF ERUPTIONS.  
SKETCH-MAP, FIG. 13.

#### I. INTRODUCTORY.

THE volcanic groups which border the Bay of Naples on its northern and eastern periphery culminate in the most famous and imposing volcano of southern continental Italy—Mte. Somma and Vesuvius. As a single volcanic edifice it presents certain features analogous to those of Roccamonfina, Mte. Vulture, and Epomeo of Ischia ; but it differs fundamentally from its nearest neighbour the Phlegræan Fields, where the eruptive energy, by repeatedly shifting its axis, scattered its forces and thus produced an agglomeration of relatively low volcanoes less than half the height of the great centralized edifice of Somma-Vesuvius. The commanding position of that volcanic mountain, rising from the Neapolitan Campania close to the sea, its ready accessibility from all sides, its imposing eruptive phenomena, and the ease with which they can be studied, all these have made it a universal centre of attraction, and inspired writers both in prose and poetry perhaps more than any other single mountain in the world.

Unlike Epomeo of Ischia, the records of whose eruptions date back to the eighth century B.C., the volcanic character of Somma-Vesuvius was unknown to, at least is hardly mentioned by, the ancients—a fact which points to a long period, perhaps 1,000 years or more, of repose before the advent of the Christian era. Both Lucretius (98–55 B.C.) and Virgil (70–21 B.C.) refer to *Mons Vesuvius* (later “Mte. Somma”); Vitruvius mentions it (18 B.C.), and Strabo (60–20 B.C.) briefly describes it ; but it was not till Pliny the younger's circumstantial account of the great eruption of A.D. 79, in which his uncle lost his life, that the mountain came into prominent notice as a formidably active volcano. Geologically, its fame dates more especially from the paroxysmal eruption of 1631 ; since then down to the present day the international bibliography on the subject in its various scientific aspects has risen to over 2,000 publications.<sup>1</sup>

<sup>1</sup> The most complete bibliographic compilations of Somma-Vesuvius are by F. Furchheim, Naples, 1897, and H. J. Johnston-Lavis (posthumous), London, 1918.

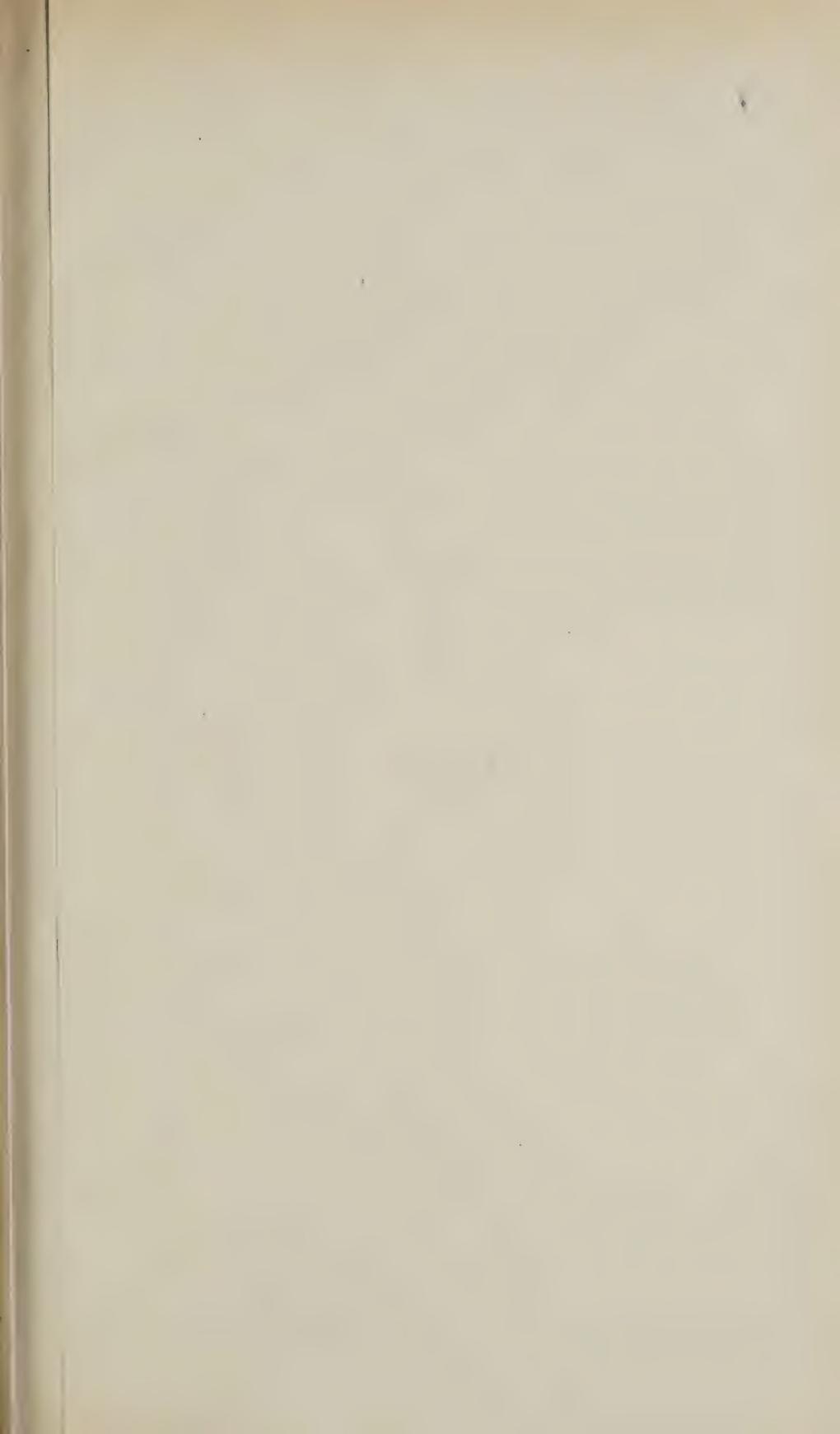
Apart from the numerous leading scientists of other countries, those in Italy who have made the volcano their special study are the directors of the meteorological and seismic Observatory on Vesuvius and the professors of the relative branches of science in the University of Naples ; the former being, since the foundation of the Observatory in 1846, M. Melloni, L. Palmieri, P. V. Matteucci, G. Mercalli, and A. Malladra, the present director ; among the latter, notably A. Scacchi, G. Guiscardi, D. P. Franco, E. Casoria, H. J. Johnston-Lavis, G. de Lorenzo, and also the late V. Sabatini, of the R. Italian Geological Survey. The constant unrest of the volcano, as shown by the virtually continuous internal volcanic activity in the intervals between external eruptions, has never ceased to keep alive scientific interest in its ever changing phenomena, carefully observed and registered in view of the always present contingency of fresh outbreaks.

## II. GENERAL FEATURES.

The centres of the two volcanic regions of Somma-Vesuvius and the Phlegræan Fields east and west of the city of Naples are 20 km. apart, but their bases almost touch each other on the eastern outskirts of the city. It is here that the superficial volcanic deposits of Somma-Vesuvius on the one hand, and the Phlegraean or Camaldoli yellow tuff deposits of the foothills of Naples on the other, are separated only by the torrent-bed of the Sebeto, which traverses the low-lying tract of the Paludi on the eastern outskirts of the city. On the north and east, the volcano is surrounded by the Campania plain, from 6 to 10 km. in width, which separates it from the Cretaceous and Tertiary foothills and spurs of the Apennines, i.e. the hills of Cancelllo,<sup>1</sup> Nola, Sarno, Nocera, Castellamare, and Sorrento, ranging respectively from 900 to 1,440 m. in altitude. Midway between the volcano and the Sarno hills flows the river of that name, whose original lower course near Pompeii was blocked and deflected by the great eruption of A.D. 79. The Sarno and the Sebeto are the only rivers east and west of the volcano ; the numerous radial streams of the latter do not, however, drain into those rivers, but, with the exception of the collecting canal of Pollena on the west, disperse in the Campania.

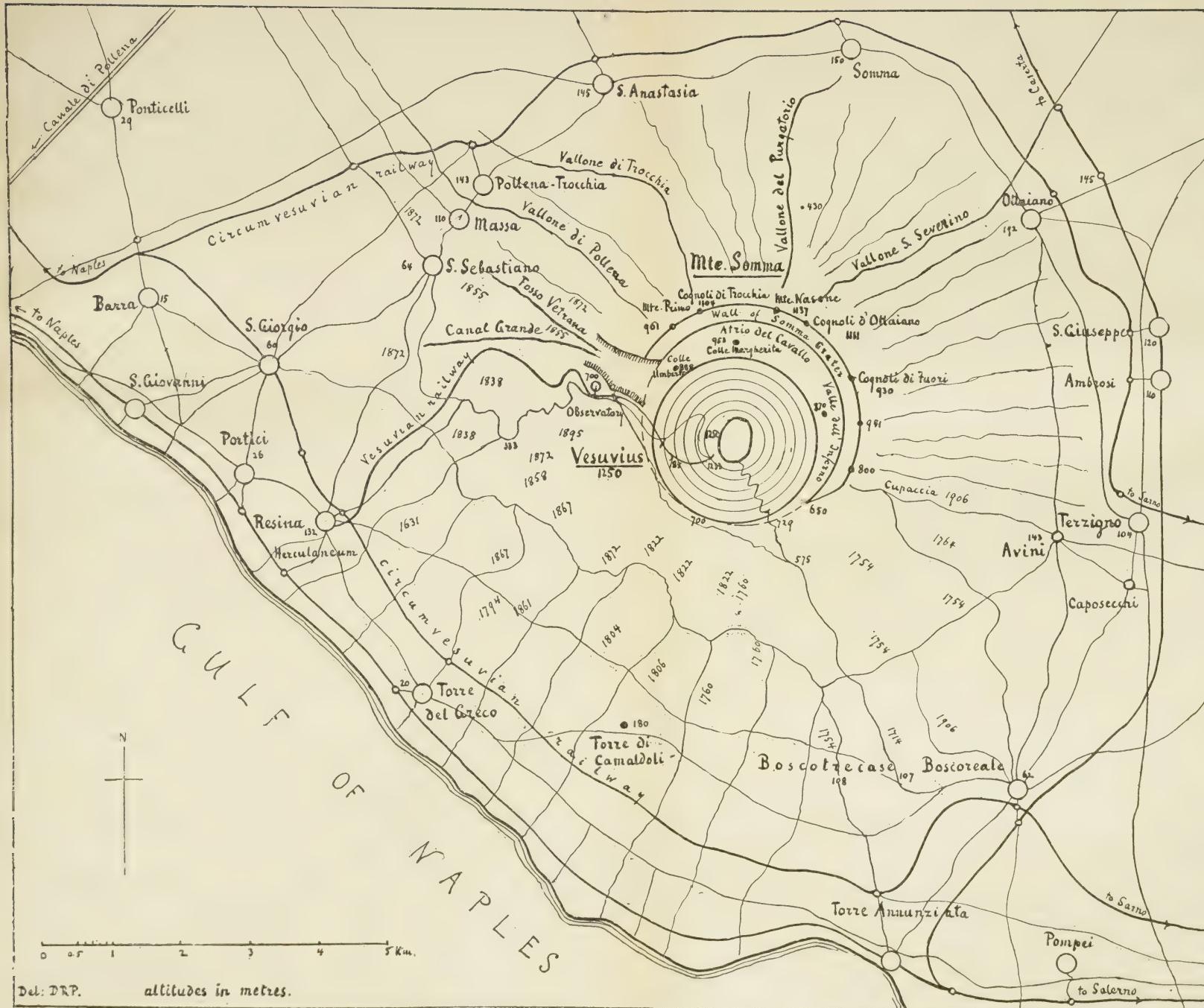
The whole base and lower flanks of Somma-Vesuvius are encircled by the Vesuvian railway and the more or less contiguous high roads. Starting from Naples and bifurcating at Barra, they link in succession the Vesuvian towns near and on the coast, i.e. S. Giorgio a Cremano, Portici, Resina (Herculaneum), Torre del Greco, Torre Annunziata, Boscoreale, and Pompeii, and, on the land side, Terzigno, S. Giuseppe, Ottaviano, Somma Vesuviana, and Anastasia, which vary from 60 to 140 and 190 m. in altitude. Indirectly the railway also serves the towns on the north-western flank along the

<sup>1</sup> Cancelllo is situated at the entrance of the historically famous defile of the Caudine Forks.



Somma-Vesuvius.

Fig. 13.



The figures converging towards the summit indicate the years of eruption and the respective lava flows.

[To face p. 102.]

road from S. Giorgio a Cremano to Anastasia, i.e. S. Sebastiano, Massa di Somma, and Pollena di Trocchia at 145 to 175 m. in altitude. The mountain is thus readily accessible all round from its base to the summit. All the places enumerated are inseparably bound up with the volcano, whose eruptions have over and over again devastated them in turn. But so irresistible is the lure of the exuberant fertility of the volcanic soil that the towns have always been rebuilt and the vineyards and orchards always replanted wherever possible. Thus, in spite of the ever-present menace of fresh devastations, the lower slopes of Somma-Vesuvius and the surrounding Campania constitute one of the most densely populated rural districts of Italy, the population around the base of 200 sq. km. being 200,000, or 1,000 inhabitants per sq. km. (2,500 per sq. mile), equal to that of the Catania district at the base of Etna. The well-known Vesuvian railway, composed of a lower, in part rack and pinion, and an upper, funicular section, runs from Resina up to the Observatory ridge, a spur of Mte. Somma, 600 to 700 m. in altitude, at the base of the cone of Vesuvius.<sup>1</sup>

### III. THE VOLCANIC EDIFICE.

#### 1. *The Platform.*

The platform upon which the volcano directly rests is mainly of submarine formation, in which the grey trachytic Campania tuff and other products are derived from the Phlegræan Fields, in part also from the basaltic products of Roccamonfina, as is evidenced by a boring, 177 m. in depth, carried out in the Campania at Ponticelli, midway between Naples and Vesuvius.<sup>2</sup> In the uppermost part of this section the Phlegræan trachytic and non-leucitic deposits are overlain by 45 m. of leucitic, basanitic Somma lava, upon which rest 60 m. of pozzolana and marine sand, also of Somma origin. The presence of an abundant fauna of marine Pleistocene conchifera both in the upper and lower deposits of the section shows them all to be of submarine, early Quaternary origin, and thus affords conclusive evidence that at that period the platform of Mte. Somma, composed of submarine volcanic expanses, was still submerged in a bay which covered the Campania and formed part of the Gulf of Naples. It was on this platform, gradually raised during the recession of the sea, that the subaerial volcano of Mte. Somma was built up in the middle and recent Quaternary and the prehistoric period.

The essential difference between the volcanic products of the

<sup>1</sup> The wire rope section, 800 m. in length, running up the western slope of the cone to the crater rim, was demolished by the eruption of 1906, but has been reconstructed.

<sup>2</sup> The Ponticelli boring passed in descending order through the following deposits : 60 m. pozzolana and marine sand ; 45 m. leucitic (Somma) basanite ; 2 m. trachytic (Campania) breccia and pumice ; 42 m. grey fine volcanic (Campania and Roccamontefina) sand with basaltic fragments ; 15 m. greenish-grey pozzolana with marine conchiglie ; and 13 m. brown breccia, pozzolana, and pumice.

Phlegræan region and those of Somma-Vesuvius consists, as already mentioned, in the former being trachytic and non-leucitic, the latter basanitic and leucitic. This difference points to their differently constituted magmatic reservoirs being separated by a subterranean barrier, though the products of both afford proof of the potent action of salt water, due to infiltrations from, and therefore connexion with, the sea.

The seat of the magmatic reservoir below the surface of the platform of Somma-Vesuvius must be considerably lower than the contact of the lowest submarine volcanic deposits of that platform with the subjacent sedimentary formations. Although, as previously stated, the Cretaceous limestone beds of Castellamare and Sorrento, overlain by Eocene sandstone, are not more than 10 km. south-east from the base of the volcano, they dip north-eastward below the volcanic platform at so steep an angle that the boring of 177 m. at Ponticelli did not reach them, and that in the artesian wells of Naples they were reached only at a depth of 433 m. Below Somma-Vesuvius the sedimentary strata would, at the same angle of dip, be struck at 300 m. below sea-level. Hence it is from that depth downwards that the ejecta of limestone blocks and fragments during the eruptions of Somma and Vesuvius are derived. The platform of Somma-Vesuvius is thus composed of about 300 m. of volcanic products. Assuming the thickness of the sedimentary substratum, i.e. of the Cretaceous limestone, marl, and Eocene sandstone strata, to be 700 m., the seat of the magmatic reservoir is probably at a depth of not more than 1,000 m. below sea-level, or 2,000 m. below the crater floor on the summit. The formula on p. 79 gives the same depth.<sup>1</sup>

## 2. Mte. Somma.

The isolated massif of Somma-Vesuvius, which dominates the Campania and Bay of Naples, presents, as seen from the west, i.e. from that city, the two summits of the prehistoric and historic cones, rising to 1,137 and 1,250 m. above sea-level respectively. The jagged ridge of Somma, semicircular in form and 5 km. in length, culminates in its northern sector, Mte. Nasone (1,137 m.), and thence decreases in altitude on either side, the principal points on the western sector being Cognoli di Troechia (1,104 m.) and Mte. Primo (961 m.), and on the eastern sector Cognoli di Ottaiano (1,111 m.), Cognoli di fuori (930 and 800 m.), and the extremity (650 m.). This semicircular ridge constitutes the remains of the great cone and crater ring of Mte. Somma,  $3\frac{1}{2}$  km. in diameter, whose western and southern sectors were breached and demolished by the first great historic eruption of A.D. 79.

Upon the floor of that crater of Mte. Somma, at 750 to 800 m. altitude, i.e. 300 to 400 m. below its rim, was superposed, probably

<sup>1</sup>  $D = \frac{V}{r^2 \pi}$ ;  $V = 27,000,000$  cub. m., the largest lava flow on record (1794);  $r = 20$  m. radius of the chimney, diam. 40 m.

during that same eruption of A.D. 79, the cone of Vesuvius, which, in the course of later eruptions, gradually rose to a height of 500 m., or 1,300 m. in altitude, thus overtopping the Somma ridge by about 200 m. Its centre is not exactly concentric with the Somma crater, but lies about half a km. to the south, and its eruptive axis is even now constantly changing, though only within the limits of its own crater. Thus the cone of Vesuvius is built up eccentrically on the crater floor of the Somma, so that on the whole western semicircle where the Mte. Somma cone-ring was breached and demolished, the flanks of the two cones are continuous and merged into each other, those of Mte. Somma having, moreover, been more or less completely covered by the products of the successive eruptions of Vesuvius.

The semicircular trough or corridor between the imposing inner wall of the Somma cone, 300 m. in height, and Vesuvius in the northern and eastern sectors is known as the Atrio del Cavallo and the Valle dell' Inferno respectively. In this corridor, 5 km. in length and about 1 km. in width, which is gradually being filled up by the ejecta of Vesuvius, rise the three cupolar bosses of lava and scoria which were formed during the eruptions of 1891-4, 1895-9, and 1903-5, respectively called Colle Margherita, 150 m. high above the corridor floor, Colle Umberto 100 m., and the third 70 m. high, the former two being in the Atrio, the latter in the Valle dell' Inferno. An interesting outcrop and remnant of the original Somma cone-ring in the demolished western sector is the Eremo or Observatory ridge at 600 m. altitude, as previously mentioned, which has hitherto always escaped the eruptions of Vesuvius and is still covered with vegetation.

Unlike the other volcanoes of Southern Italy, including Etna, Somma-Vesuvius exhibits no external or parasitic cones on its flanks, the only exception being the old lava boss—not a cone—of Torre Camaldoli at 185 m. altitude between Torre del Greco and Torre Annunziata. During eruptions of lava flows from fissures, or other points of least resistance called “bocche” or vents, small cones are often formed in rows over the points of issue, but they are so unstable that they are nearly always swept away by torrential rains and mud-flows.

The base of Mte. Somma is practically circular, 8 km. in radius, the circumference being thus 50 km. and the superficial area covered by the mountain 200 sq. km. On its southern flank, i.e. on the side of the sea, as also on its eastern and western flanks around the Campania plain, Mte. Somma rises at an average angle of 10 degrees, while the northern slopes are much less steep, not exceeding 3 degrees. All round the Somma flanks the uniformity of the rise of slope is, however, considerably modified by a concave, parabolic curve of denudation in addition to the natural tendency of the mountain mass to settle by its own weight. The radial ravines of the mountain sides, most of them fractures due to earth-shocks, later deepened by the erosion of the descending streams, exhibit generally three

sections; the highest and steepest, from 600 to 1,000 m. altitude, being that of the sources and ramifications of the streams; the middle section, from 300 to 600 m. altitude, in which the erosion is most active and hence the concavity most pronounced, the lava and tuffs banks being here eroded into numerous horseshoe cascades; and the lowest and flattest section, from the base to 300 m. altitude, being that of the characteristic torrent beds or *lagni*, which generally collect several streams and at their lower ends disperse in rivulets that either sink into the permeable volcanic soil or are canalized for irrigation of the vine and fruit plantations. The volcanic material carried down by the streams is, during its transport, gradually sifted and clarified, so that the rivulets dispersing from the *lagni* are charged with and deposit the finest pale grey volcanic ash and sand. It is this material which constitutes the superficial soil of the cultivated belt of the lower slopes and base of the mountain and is the source of the exuberant productivity, fertility, and luxuriance of the famous district. Above that belt, i.e. from about 250 m. altitude upwards, vegetation consists chiefly of wild chestnut-trees, brushwood, or *ginestra* up to 650 m. altitude, above which the flanks of the mountain are more or less barren.

Among the principal ravines, called *valloni*, *fossi*, or *canali*, which radiate from the semicircular cone sector of Mte. Somma, are notably those of S. Severino on the north-eastern, del Purgatorio on the northern, and of Trocchia, Pollena, Vetrana, and Valle Grande on the western flanks. All of these reveal natural sections of the successive products of eruption between the contour lines of 200 to 600 m. and above, the exposures being from 20 to 80 and 120 m. in height. One of the most important and, during heavy rains, most torrential *valloni* is that of Pollena which, at its lower end, drains into the Pollena collecting canal, 7 km. in length, with its outlet to the sea. Another notable ravine is the gap between the Observatory ridge (700 m.) and the opposite ridge of Mte. Primo (961 m.), the western extremity of the old Somma cone sector. Below the low bar of lava which links the base of those two spurs the gap expands and divides into two arms, one the Canale della Vetrana to the west, and the other, Canal Grande, to the south-west, both of which have repeatedly served as outlets of great lava flows descending from Vesuvius through the Atrio del Cavallo. Another similar gap is that at the eastern extremity of the Somma cone sector, at 900 m. altitude, through the Cupaccia ravine, which has repeatedly served as outlet of great lava flows descending on the eastern flank towards Terzigno. The northern flanks and base of the mountain owe their protection from the invasion of lava flows to the great Atrio wall of the Somma cone which compels the lavas issuing from the northern sides of Vesuvius to find their exit through the two gaps referred to.

In the lower parts of the ravines all round Mte. Somma are piled up the eroded masses of coarser material, scoria, breccia, and débris,

which, when set in motion by the streams being in flood, sometimes block and deflect the latter, or when carried further down, devastate the cultivated belt. Although the annual rainfall on Somma-Vesuvius is only 785 mm. (32 inches), the rains, falling after long intervals, are so heavy that they enormously increase the transporting and eroding force of the streams, albeit a large percentage of water is at once absorbed by the volcanic soil of the flanks.

Other agents of more or less potent denudation are the action of frost, which splits the lava and tuff banks and breaks the upper masses up into blocks; the action of heat, which, by producing evaporation, vapour, and expansion, crumbles the saturated tuff and scoria; the action of high winds<sup>1</sup> upon loose ashy and other material, and lastly, the shaking and shattering action of earth-shocks, to which many of the radial fractures and ravines of the mountain sides are primarily due.

A noteworthy feature of the valloni of Mte. Somma is that the width of their upper sections is often disproportionately large in respect of the size and erosive power of the streams. Although this phenomenon is in great part due to the collective action of the different agents of denudation, it also points to these valloni having originally reached higher levels than at present. Hence it is probable that the cone of Mte. Somma was at one time a few hundred metres higher than it is now. The hypothesis that it was double its present height is, like the similar hypothesis applied to other volcanoes of Southern and Central Italy, an exaggeration devoid of evidence.

### 3. *Vesuvius.*

As previously stated, Vesuvius is eccentrically superposed on the old crater floor of Mte. Somma, the still visible part of that crater floor being the corridor of Atrio del Cavallo and Valle dell' Inferno, which separates the cone of Vesuvius from the great semicircular crater wall of the Somma cone. Compared with that magnificent wall which, 5 km. in length and 300 m. in height, at an angle of 45 degrees, exhibits hundreds of lava flows piled upon each other, the cone of Vesuvius presents all the characteristics of its relatively recent origin, composed, as it is, entirely of more or less incoherent ashes, pumice, and scoria. Hence it is in a state of unstable equilibrium, subject to concussions, partial collapse, and demolition by earth-shocks or by the explosive eruptions from its crater.

The roughly circular base of the ash cone is  $2\frac{1}{2}$  km. in diameter, the present height 500 m. or 1,250 m. in altitude at its highest point, and the present elliptic crater rim 750 m. in its major, and 500 m. in its minor axis, or 1 km. in circumference. Its outer, or cone-slope

<sup>1</sup> The exposure of the mountain all round renders it at all times peculiarly liable to the action of high winds. During great explosive eruptions, stupendous atmospheric disturbances are generated by the Plinian ash clouds, which carry ashes to distances of hundreds of km.—e.g. to the Balkans, Africa, etc., the distance being in direct relation to the height to which the pine-cloud is projected.

rises at an angle of 35 degrees, the inner, or crater slope descends precipitously at 45 degrees to the crater floor, which lies about 300 m. below the cone-rim. The crater thus exhibits the form of an inverted cone or funnel whose steep walls of loose material are more or less variable and insecure. During quiescence the depth of the crater varies according to the occasional ejecta of the vent, and also according to the material which tends to constantly slide back from the crater walls and fill up the crater floor. After paroxysmal eruptions the depth of the crater is generally much greater than before, until the vent again becomes temporarily plugged and the crater floor is raised by accumulating material and the deposits of fumaroles which continue active around or near the vent. The height of the cone and the depth of the crater vary with every paroxysmal eruption. Before the eruption of 1904 the height was 450 m. above the floor of the Atrio ; that eruption raised it to 580 m., while that of 1906 lowered it again to its present height of 500 m. The tendency of great paroxysmal eruptions is generally to demolish the cone, the tendency of intermediate feeble eruptions is to reconstruct and raise it.

Unlike Mte. Somma, the form of the cone of Vesuvius is convex, like a truncated cupola, and its slopes are furrowed by deep ruts radially and so regularly disposed all around the surface that the latter has the appearance of having been ploughed, or of being grooved, like a half-open umbrella, a phenomenon produced by rain water on the steep incline of 35 degrees. The dark ash-grey colour of the cone superposed on Mte. Somma like a huge cap presents a vivid contrast to the brown tint of the flanks of the latter, and albeit both are built up much in the same way, the marked difference in their appearance stamps them as belonging to different periods, Somma being of prehistoric, Vesuvius of historic origin. Prominently though the latter figures as the central vent, it is, after all, only the terminal cone, in area  $\frac{1}{30}$ th, in volume  $\frac{1}{80}$ th of its parent.<sup>1</sup> After 2,000 years of activity it may still increase in volume, though hardly in height ; but, like the terminal cone of Etna, to which it is about equal in size, it is always liable to collapse by paroxysmal explosions.

#### IV. THE PREHISTORIC AND HISTORIC PERIODS OF ERUPTION.

##### 1. *The Prehistoric Period. Mte. Somma.*

It is a curious fact that the dividing line between the prehistoric and the historic eruptions of Mte. Somma-Vesuvius coincides with the advent of the Christian era. In the absence of historic records of the eruptions of Mte. Somma, all of which, except the great eruption of A.D. 79, took place before that era, the term prehistoric

<sup>1</sup> Considering Somma-Vesuvius roughly as a pyramid, its total volume is 200 sq. km.  $\times$  0.4 ( $\frac{1}{3}$  of its height) = 80 cubic km. Of this the cone of Vesuvius is 7 sq. km.  $\times$  0.175 ( $\frac{1}{3}$  of its height) = 1.22 cubic km. or  $\frac{1}{80}$  of the whole mountain.

applies to the volcanic phenomena authenticated only by the evidence and sequence of the products of eruption, i.e. of lava flows as effusive, and of tuffs and allied material as explosive, products deposited prior to the formation of Vesuvius. The inference that the great eruption of A.D. 79, which gave birth to Vesuvius, must have been preceded by a long period of repose, is warranted primarily by the almost total absence of all mention by the ancients of either Somma or Vesuvius *as a volcano*. The only exception is a vague reference by Vitruvius Pollio, a military engineer in the time of Cæsar and Augustus, in his writings of 18 B.C. (*De architectura*), as to the mountain having once burst and covered its surroundings with fire, an event which may be founded on the legendary tradition quoted by the Greek historian Diodorus Siculus in 60 B.C. that Hercules saw the mountain in a fiery state similar to that of Etna. The Greeks of the seventh and fourth centuries B.C., whom the eruptions of Epomeo of Ischia drove from that island to the mainland where they founded Cumæ, Baia, and Naples in succession, would hardly have settled on that coast if Mte. Somma had been a repetition of Epomeo; at least, they would have recorded any eruptions of the former, as they recorded those of the latter and dreaded even the reputed fire and flame of the Phlegræan Fields. The last quiescent period of Mte. Somma must therefore have lasted at least 1,000 years, an interval equal to that between the last great eruptions of Epomeo of 470 B.C. and A.D. 1320.

The question whether Vesuvius proper existed before the eruption of A.D. 79, or whether it came into existence at that time or later, has been fiercely discussed. Strabo briefly relates that in his time (60–20 B.C.) the mountain was clothed with vegetation, the summit was flat, covered with trees, and exhibited in the centre a hollow depression in which some warm pools of water were surrounded by burnt soil. Even before him Spartaeus, after escaping from Capua in 73 B.C. with his band of gladiators, sought refuge in the mountain and crossed its wooded steep slopes into Lucania. All this tends to the crater of Mte. Somma not being at that time surmounted by Vesuvius, but being in repose, and the whole mountain being clad with verdure and vegetation, as Roccamontfina, Epomeo, and Mte. Vulture are now. The paroxysmal eruption of a hundred years later wrought a complete change in the mountain.

The most accessible and imposing exposure of the prehistoric products of Mte. Somma is the crater wall already mentioned, which rises from the Atrio del Cavello to the cone-rim culminating in Mte. Nasone. The countless lava flows with intermediate banks of scoria, pumice, ashes, and sand are all piled up in this escarpment at an angle of 45 degrees in apparently inextricable confusion, but really in the order in which they were ejected. In some places the lavas form continuous masses, in others dykes, in others they are twisted and interlaced with the allied products densely packed and fused together by heat and pressure under high temperature. In

others, again, the lavas are sheathed in a vitreous crust or *saal* band ; in the dykes the lava is more porous and vesicular. Neither the lavas, essentially basanitic and tephritic, with large leucite and abundant augite and olivine phenos, nor the explosive products differ from those of the earlier historic down to the most recent eruptions. They show the Somma eruptions to have been very similar to those of Vesuvius, that is, of highly leucitic lava flows preceded or accompanied by violent explosions of lapilli, pumice, sand, and ashes, together with bombs and myriads of fragments of sedimentary and igneous material torn from the walls of the chimney by the magma in its upward passage. Assuming, for the sake of illustration, the average thickness of the products of each consecutive eruption to have been 5 m., the wall 300 m. in height would represent sixty eruptions, apart from those which built up the bulk of the mountain.

Besides the great Atrio escarpment, the Observatory ridge, and other localities previously mentioned, notably on the southern base of the mountain and at Pompeii, instructive, because consecutive and superposed exposures of the products of the Somma eruptions, are those in the radial fracture ravines already referred to. Johnston-Lavis<sup>1</sup> used the natural sections of these valloni for evolving an elaborate scheme of the volcanic history of Mte. Somma, which he divided into eras, phases, and subdivisions of periods. The scheme rests on the more or less uniform sequence and superposition of the products in these natural sections, which, linked together and combined from nine valloni, are intended to represent the gradual building up of the mountain, the character and varying thickness of the exposed deposits being the index of paroxysmal or feeble eruptions with intermediate periods of repose. The scheme and the combination of the sections are to a great extent fanciful, more especially in respect of the great Atrio wall which, crowning the mountain and therefore constituting one of the last periods of Somma eruptions, should obviously figure in the concluding phase, whereas it is placed in the first phase as if it were at the base of the mountain. Apart, however, from the labour bestowed on the scheme, its value consists mainly in the tangible evidence of several protracted periods of repose between periods of paroxysmal and feeble eruptions. The periods of repose are characterized by strata or layers of yellow and brown earthy soil or humus, intercalated between subjacent and overlying volcanic products, i.e. lava, scoria, breccia, and pumice. These layers of earth, which are up to 2 m. in thickness and occur in the lower, middle, and upper sections of the nine valloni between 200 and 600 m. altitude, are derived from originally volcanic, but completely decomposed material rendered organic by the same process which generates vegetation on the disintegrated and decomposed lava and tuff surface in our own day, one hundred years being, by

<sup>1</sup> H. J. Johnston-Lavis, "Mte. Somma and Vesuvius": Q.J. Geol. Soc., 1884, p. 35 et seq.

tradition and experience, generally required for covering such volcanic soil with vegetation. As relatively recent instances of this may be mentioned the Vesuvian lava flows of 1767 and 1794, whose lower courses on the southern flanks of the mountain are already obliterated by renewed vine and fruit plantations stimulated by the alkali and phosphates of the disintegrated lava. The three periods of repose of Mte. Somma were also periods of active denudation, which promoted vegetation by the agency of copious streams charged with fertilizing volcanic material. During these periods the volcano must have exhibited the appearance of an ordinary, domal mountain, wooded and covered with vegetation as Strabo depicted it in the last of those periods, and as the extinct Italian volcanoes previously described present themselves in our own day. During the first two of those periods, the mountain was, of course, only about two-thirds and one-third of the height it attained in Strabo's and the present time.

For the rest, the sequence and varying thickness of the volcanic products exposed in the valloni point to long protracted periods of explosive and effusive eruptions, according to the predominance of lavas over tuffs and vice versa, some of the deposits being no less than 20 to 50 m. in thickness, and thus attesting the magnitude of the eruptions. The deposits of greatest thickness, pointing to paroxysmal eruptions, generally overlie immediately the layers of vegetable soil, while the periods intermediate between the maxima and the next minima of thickness mark a general decline of volcanic activity. Accordingly, the history of prehistoric Mte. Somma down to the great eruption of A.D. 79 may, in the present writer's view, be summed up in the following six periods:—

- I *Period*.—Rise, climax, and decline of volcanic activity.
- II *Period*.—Repose, mountain covered with vegetation.
- III *Period*.—Paroxysmal eruptions and gradual decline.
- IV *Period*.—Long repose, mountain higher and covered with vegetation.
- V *Period*.—Paroxysmal eruptions and gradual decline.
- VI *Period*.—Repose till A.D. 79; mountain about present height, covered with abundant vegetation.

## 2. *The Historic Period. Vesuvius.*

The eruptive manifestations of Vesuvius may be classed under three designations which have come into vogue within the last twenty years in relation to active volcanoes generally:—

(1) Plinian eruptions which, like the one of A.D. 79 described by Pliny the younger, are violently paroxysmal, accompanied by the traditional pine-shaped cloud of ashes, lapilli, pumice, bombs, etc.;

(2) Strombolian eruptions restricted, like those of Stromboli in the Lipari Islands, to relatively feeble explosions of molten lava fragments and other material, which is deposited on the rim of, or falls harmlessly back into, the crater; and

(3) Vulcanian eruptions which, like those of Vulcano, also in the Lipari Islands, only emit lava without explosive phenomena.<sup>1</sup>

Plinian eruptions tend to demolish the cone, the others tend to reconstruct the demolished parts. The synopsis of the principal eruptions in Section VII of the present paper shows an evolution of cycles of volcanic activity similar to that of Mte. Somma. The maxima and minima, that is, the climax of the paroxysmal eruptions and the anticlimax of repose which determine the cycles down to the present day, are briefly dealt with in the following rapid survey of the alternate rise and fall of volcanic activity.

*Eruption of A.D. 79.*—The inference that, as previously stated, this eruption was the first after a long repose is strengthened by the very fact of the extreme paroxysmal violence of the explosion due to the long accumulation of eruptive forces of molten material, gases, and steam in the magmatic reservoir whose outlet was through a single vent. The cataclysm which blew up the great Somma crater 4 km. in diameter, demolished the southern and eastern semicircle of the cone-ring, and piled up on its ruins the cone of Vesuvius, was heralded by a succession of premonitory earthquakes lasting intermittently from 63 in the reign of Nero, to 78 and 79 in the reigns of Vespasian and Titus. As is well known from the circumstantial letters of the eye-witness Pliny the younger to Tacitus, the effects of the eruption buried Herculaneum under an ash shower followed by a formidable *lava d'acqua* or torrential volcanic mud-flow to a depth of 8 m.; overwhelmed and wiped out Pompeii, till then a port on the sea-shore, with deluge showers of ashes and pumice 5 m. deep; blocked and deflected the course of the river Sarno; buried under ashes even the town of Stabiae (near the present Castellamare, where Pliny the elder perished from suffocation); and covered with ashes and other ejecta the Castellamare hills and Mte. S. Angelo (1,440 m.), 400 m. higher than Mte. Somma, and 25 km. distant from the seat of eruption. During this eruption was formed the lower part of the cone of Vesuvius, whose crater thus took the place of the demolished one of Mte. Somma. The mantle of fine white ash and pumice with which Pliny saw the mountain and surrounding district covered at the end of the eruption, has been, in a lesser degree, the final phenomenon of great eruptions ever since, these fine white ash showers marking the last stage of the explosive forces.

*Eruptions of 471-3 and 512.*—Both these eruptions were violently explosive; in the former the wind-blown ashes were carried as far as Constantinople, while in the latter the devastations all around the mountain base and in the Campania were so great that King Theodoric of the Goths relieved the suffering districts from taxes.

*Repose 1500 to 1631.*—Scant records of the dark and middle ages

<sup>1</sup> There is no distinct border line between strombolian and vulcanian eruptions. Mercalli, after the 1888 eruption of Vulcano, found large ejected blocks 1 km. from the small crater.

mention six eruptions between the seventh and fifteenth centuries, showing that volcanic activity continued intermittently down to about 1500, during which period the original cone of Vesuvius was gradually raised by the ejecta of feeble eruptions to 700 and 1,200 m. altitude, thus slightly overtopping Mte. Somma. About 1500 a repose set in which lasted about 100 years down to the great eruption of 1631. During that quiescent period the mountain once more clothed itself with a mantle of verdant vegetation; so much so that, as recorded by Sorrentino,<sup>1</sup> just before the cataclysm of 1631 the Atrio del Cavallo was a verdant corridor, the cone and filled-up crater of Vesuvius were wooded, and a hollow in the crater floor was occupied by some warm lakelets. This was thus a precise repetition of the repose period in Strabo's time, 1600 years earlier.

*Eruption of 1631.*—This great eruption constitutes a landmark in the history of the volcano as inaugurating a new protracted period extending down to the present day. The explosion began amid earth-shocks with a great rift in the southern flank of the ash cone, and an enormous pine-cloud whose ashes, lapilli, pumice, and bombs fell thickly all around the flanks and base of the mountain, and, blown by high winds, travelled as far as Taranto and the Adriatic, 200 km. distant. The huge lava flows which immediately followed the explosion and poured out through rifts in the cone, were no less than five in number, on the south-east, south, and south-west, overwhelming respectively Boscotrecase and Torre Annunziata, Torre del Greco Resina and Portici, S. Giorgio a Cremano and S. Giovanni Teduccio, and lastly the district of Massa di Somma, this fifth stream passing through the Atrio and the Observatory gap down the Vetrana ravine. The first two lava streams flowed into the sea to distances of 200 and 400 m. from the shore; the third formed the boss or promontory of Granatello between Resina and Portici. As usual, torrential mud-flows rushed in different directions down the flanks and completed the ruin and havoc already wrought by the lava flows. The great feature of this paroxysmal explosion consisted in the partial demolition and considerable lowering of the ash cone to a level below that of Mte. Somma, and the formation in the reduced cone of a large funnel-shaped crater whose apex was more than 700 m. in depth below the rim, i.e. lower than the floor of the Atrio.

*Eruptions 1660–1794.*—In the eruption of 1660 a new terminal cone was formed in the enlarged crater of 1631; it grew during the eruption of 1682, after which it was sufficiently high to overtop Mte. Somma. By that time the lava and mud-flows of Vesuvius had covered all the upper and in great part also the middle and lower flanks of Mte. Somma on the south-east, south, and west, so that the distinction between the two mountains was on that side obliterated, and they presented one continuous slope. The eruptions of 1714, 1737, 1751, 1754, and 1757 from rifts in the cone produced

<sup>1</sup> I. Sorrentino, *Istoria del Mte. Vesuvio*, Naples, 1834.

lava flows notably on the south-eastern and southern flanks. The eruptions of 1760 and 1767 were chiefly remarkable for the shifting of the lava vents from the cone to the southern lower flank of the mountain. In 1760 a large fissure suddenly opened above the Camaldoli boss at 300 m. altitude, surmounted by fifteen small parasitic cones; the lava flow vomited by the fissure reached the sea between Torre del Greco and Torre Annunziata. In 1767 a similar fissure opened between Torre del Greco and Resina to the west of the one of 1760, throwing up a large flow of incandescent lava. After a great explosive eruption in 1779 the climax was reached in the great eruption of 1794, when a rift 600 m. in length and 30 m. in width suddenly opened above Torre del Greco, at 600 m. altitude, and an enormous liquid lava flow, computed at 27 million cubic metres, overwhelmed and destroyed that town, reaching the sea, 4 km. distant from the rift, in the space of four hours. Although of considerable magnitude, these vents, formed in the lower, old flank of Mte. Somma, do not denote a shifting of the eruptive main axis, but are branch outlets of the trunk chimney, the rising lava finding through them an easier and lower exit than through the cone of Vesuvius itself. That cone participated in these eruptions by its usual, though less violently explosive phenomena which culminated in 1794 in the collapse of the inner cone of 1660, leaving the roughly circular crater of the original cone.

*Eruptions 1804-72.*—In 1804, 1806, and 1822 the shifting of the lava outlets was maintained by lava flows issuing from fissures even nearer the Camaldoli hill, at 200 m. altitude; but from 1834 onward, the vents were again displaced to the cone, on whose south, north, and west flanks explosive rifts opened in 1822, 1834, 1850, and 1855 with large lava flows, of which the first poured down the south flank towards Resina, the second (6 km. long) through the Cupaccia gap down the east flank to Caposecchi,<sup>1</sup> and the others through the Observatory gap on the west. The lava flow of 1855, the most formidable of that period, divided into two arms, one flowing south-west towards S. Giorgio a Cremano, the other flowing west between and beyond Massa and S. Sebastiano into the Campania plain to a distance of 5 km. from the seat of eruption, one of the longest Vesuvian flows on record. The volume of this flow was computed at 17 million cubic metres.

*Eruption of 1872.*—This great paroxysmal eruption, one of the landmarks in the history of the volcano, was initiated by a violent explosion, by which the cone was cleft from top to bottom on the north flank. From this cleft issued an enormous mass of liquid lava, which, following the course of the 1855 flow, poured through

<sup>1</sup> Cupaccia—a bad hollow—is a derivative of *cupa*, a trough or gully, often 20 m. deep, formed in soft volcanic soil by the trailing of brushwood down the mountain side and deepened and widened by erosion. The 1834 lava flow was one of the longest and most formidable in size, equal to that of twenty-one years later (1855). The lava is now quarried at Caposecchi, the terminal of its flow.

the Atrio and the Observatory gap towards Massa, with a branch to S. Giorgio a Cremano. The great pine-cloud of ashes, bombs, and sand covered the whole mountain and surrounding district with a mantle of ash, the finest sand and ashes being blown as far as Sicily. In this classic eruption the cone once more underwent a change, consisting in a new central terminal cone being formed in the crater. This new superposed and pointed cone had a relatively small ring 250 m. in diameter, and its crater was 200 m. in depth; the height of Vesuvius was thereby raised to 1,330 m. altitude, the highest on record. The volume of the new cone was about 12 million cubic metres.

*Eruptions 1891-1904.*—Upon the great paroxysm of 1872 followed a period of relative exhaustion or recuperative quiescence of twelve years to 1884. The eruptions from 1885 and 1891 to 1904 were mainly intermittent, marked by lava flows from the northern and western base of the cone, which took the usual course down through the Observatory gap. It was these particularly viscous, sluggish lavas that piled up the three lava and scoria cupolar mounds of Colle Margherita and Colle Umberto in the Atrio, and a third one in the Valle dell' Inferno. As previously mentioned, these mounds and lava flows add considerably to the filling up of the Atrio corridor.

*Eruption of 1906.*—This, the most recent paroxysmal eruption, constitutes the climax of the preparatory eruptions of 1891 to 1904.<sup>1</sup> The demolition wrought by the cataclysm of 1872 had been largely repaired by feeble eruptions within the crater, which filled up the crater floor and reconstructed the shattered walls, while the new terminal cone maintained its height and volume. In 1905 an almost continuous lava flow from a fissure in the principal cone at 1,175 m. altitude marked the advent of more intense activity, which in the early part of 1906 was accentuated by projections of ashes and incandescent scoria, accompanied by earth-shocks. On the 4th of April a rift opened in the south-east sector of the rim opposite the previous fissure, and lava steadily flowed from both. In the afternoon of the same day the terminal, pointed cone was blown up and collapsed, immediately followed by an enormous pine-cloud which rose obliquely from the crater and descended on the south-west flanks, the Campania, and Naples. Later a rift opened at the southern base of the cone at Bosco di Cognoli, near the extremity of the Somma ridge, at 845 and 900 m. altitude respectively, the extremely liquid lava flow advancing rapidly south, where it overwhelmed Boscotrecase and arrived at the upper end of Torre Annunziata. A second flow from a fissure to the north of the first advanced east through the Cupaccia gully towards Terzigno.

<sup>1</sup> One of the best scientific descriptions of the 1906 eruption is the late V. Sabatini's, Professor of Vulcanology in the University of Rome, and a Member of the It. Geol. Survey: *Boll. R. Com. Geol.*, 1906, p. 169 et seq.

During the night of 7th and 8th April, while the lava streams were devastating the lower flanks on the south, the crater ejected, amid continuous earth-shocks and roarings, a second gigantic pine-cloud with electric discharges and enormous showers of ashes, bombs, and lapilli, which descended on the northern and north-eastern flanks and base of the mountain. On 8th April the lava flows and ejections of bombs stopped, but abundant ash showers continued to fall alternately on the north-eastern and north-western flanks. In the result, Ottaviano and S. Giuseppe on the north-eastern base were in part destroyed, Resina, Portici, Torre del Greco, and Boscorese heavily damaged, while in Naples the weight of the ashes caused the Monteoliveto market hall to collapse. Torre Annunziata was providentially saved by the second explosion, which, by opening fresh outlets to the lava, relieved the pressure on the flow that threatened that town. The points of eruption of the six principal and parallel lava flows are all situated in the south-eastern sector on the flank and base of the ash cone at altitudes between 700 and 1,175 m., the lowest fissure coinciding with the altitude where the cone of Vesuvius rests on the edge of that of Mte. Somma.

As regards the cone itself, the collapse of its terminal peak lowered it by 80 m., i.e. to 1,250 m., so that after the eruption the cone presented once more the form of a truncated pyramid with an elliptic crater rim 1·5 km. in its major and 1 km. in its minor axis, and a funnel crater 400 m. in depth. The altitude of the cone was in 1904, 1,300 m.; in 1905, 1,330 m.; in 1906, after the eruption, 1,250 m. After this last eruption the cone, greatly fissured both outside and inside, was extremely unstable, because wholly covered with new ashes; the crater walls exposed here and there the older banks of lava, lapilli, and ashes, and at their lower ends, near the floor of the funnel, were fringed with fumaroles. On the south-eastern base of the cone slope, an enormous landslide of 300,000 cubic metres of material left a great cavity and wiped out the inn of Casa Fiorenza and the path leading up to the crater. On the western flank the wire rope railway, 800 m. in length, which ran nearly to the rim of the crater, was entirely destroyed. Ash slides outside and inside the cone are even now of frequent occurrence.

The longest lava flow was that of Boscorese,  $5\frac{1}{2}$  km., flowing at the rate of 5 km. per hour, and expanding to a width of 300 m. The maximum depth of the lava flows of the 1906 eruption was 8 m., the mean thickness  $2\frac{1}{2}$  m. The aggregate volume of the lava flows is computed at 5,700,000 cubic metres; that of the tuffs, ashes, and other solidified products at 120,000,000 cubic metres, or twenty times more than that of the lavas; the area covered by the latter is estimated at 2·3 sq. km. (about 1 sq. mile); that of the ashes on and around the mountain at 80 sq. km. (32 sq. miles). As regards the emission of lava, the eruption of 1906 was inferior to that of 1872 and of 1794, when the aggregate volume reached 17 and 27 million

cubic metres, or three and four times more respectively,<sup>1</sup> but in explosive phenomena, notably in the twice repeated pine-cloud of gigantic dimensions, the eruption of 1906 ranks as one of the greatest of the Plinian order.

1906 to 1923.—After the eruption of 1906, Vesuvius entered upon a period of relative quiescence, which has lasted down to the present time. In 1914 H. S. Washington<sup>2</sup> found a string of thirty domal fumarole mounds, 1 to 8 m. in height, mildly active at the base of the cone, in the Atrio, the vapour having a temperature of 97 degrees F. Inside the crater, near the floor, another battery was much more active at temperatures which rose in two years (1911 to 1913) from 128 to 347 degrees. Since 1906 continuous slides of material had taken place from the walls of the crater, and culminated in 1912 in a marked subsidence on the southern part of the crater floor. This was followed in 1913 by a funnel opening in the floor, 150 m. in diameter and 70 m. in depth, vomiting dense columns of white smoke. Later another incandescent funnel, 120 m. in diameter and 40 m. in depth, opened in the subsided part of the floor, which emitted yellow vapour amid loud roarings.

In 1914 the crater floor was domal in form and covered with ash and blocks; the highest point was 327 m. below the crater rim, or 80 m. less than after the eruption of 1906. In December, 1914, a small cone formed in the funnel of the south-western part of the floor, the funnel being half filled with incandescent lava.

The signs of eruptive activity which Vesuvius has shown since then have, so far, been limited to strombolian ejections inside the crater. The small cone of 1914, formed on the crater floor, was blown up in September, 1921, when the lava and scoria rose to 126 m. above the floor, but fell back into the crater. The gradual evolution of Vesuvius since the exhausting eruption of 1906 has thus been from a quiescent to a solfataric state in 1914, followed by intermittent strombolian activity in August, 1921, in February and June, 1922, and most recently, on 6th June, 1923, when a new small cone, 70 m. high, previously formed on the crater floor, vomited lava from a fissure in its flank, then collapsed, but in its reduced form continued active for several days. This strombolian activity of Vesuvius has frequently become more marked after heavy rains. It may or may not have been preparatory to a more violent outbreak, although the large size of the present crater, 1 km. in diameter and 500 m. in depth, affords ample scope for a continuance of the strombolian phase within its limits. Since 1631 the quiescent intervals of Vesuvius have not exceeded twenty years, while the mean duration of quiescence after great paroxysmal eruptions has only been seven years.

<sup>1</sup> Neither of these great lava flows of Vesuvius is equal to the stupendous lava flow of Capo del Bove, which, issuing from the Lazio volcano, crossed the Campagna to near the gates of Rome, a distance of 10 km., its aggregate volume being 45 million cubic m. *Vide Lazio*, II, p. 20.

<sup>2</sup> H. S. Washington, Bull. Geol. Soc. of America, 1915, p. 376.

In the course of its activity of 2,000 years Vesuvius has not only built up its own cone 5,000 million cubic metres in volume, but has by each of its eruptions added to the volume of its parent, Mte. Somma, in pouring lava flows over the eastern, southern, and western slopes, and in showering the concomitant ashes and other explosive ejecta over the whole mountain. The aggregate volume of lava vomited during the great eruption of 1906 was by the late V. Sabatini computed at 6 million cubic m., that of the ashes and explosive ejecta at 120 million cubic m., total 126. The great paroxysmal eruption of 1794 yielded a maximum recorded lava flow of 27 million cubic m. and a twenty-fold volume of ashes and ejecta of 540 million cubic m., total 567. In respect of the aggregate area of the mountain, i.e. 200 sq. km., those totals represent a uniformly distributed mean layer of 1.7 m. in thickness per sq. m. Of course, part of this is in the lapse of time removed by erosion, denudation, and atmospheric agency.

The history of Vesuvius since its initial formation in A.D. 79 may be summarized as follows :—

I *Period*.—Paroxysmal eruptions in A.D. 79 and 472 ; intermittent, declining activity down to 1500.

II *Period*.—Repose from 1500 to 1631 ; mountain clothed with vegetation.

III *Period*.—Paroxysmal eruptions of 1631, 1794, 1872, and 1906, with intermediate minor eruptions and brief phases of quiescence.

IV *Period*.—Repose up to 1921 ; strombolian activity 1921 to 1923.

As may be gleaned from the list of historic eruptions (Section VII of this paper), a great Plinian eruption has, since 1631, occurred once in every century, and nine violent eruptions (including the Plinian) have, in the same lapse of time, occurred at average intervals of fifty years, each of them having been preceded or followed by one of the seven relatively brief phases of quiescence. There is no record of any of the Vesuvian eruptions having coincided or been connected with those of Epomeo in Ischia or Etna in Sicily.

#### V. CONCLUSION.

The outstanding features of the origin, the periods, and the products of eruption (see Petrographic Note) of Somma-Vesuvius may be recapitulated as follows :—

1. Mte. Somma, built up on a platform of Campania tuff, began its submarine activity in early and middle Quaternary, its subaerial activity in late Quaternary prehistoric times.

2. The prehistoric eruptions (Mte. Somma), down to A.D. 79, extend over three periods of activity, with three intermediate periods of repose. The historic eruptions of Vesuvius, i.e. since A.D. 79, comprise two periods of activity with one intermediate period of repose ; the present, fourth period since 1906, is so far again a period of intermittent quiescence and strombolian activity.

3. The distinguishing petrographic features of the products of Somma-Vesuvius are the absence of trachytic lavas and the uniformity of the leucite-basanite and the leucite-tephrite lavas and their derivatives. This uniformity points to a self-contained magmatic reservoir. Its outlet is a single vent or chimney, with minor fissural ramifications, but with relatively slight shifting of the eruptive axis.

4. The ejection of sandstone and limestone blocks, the latter indurated and metamorphosed to marble by contact with the fluid magma, warrants the inference that the seat of the magma is immediately below the Eocene sandstone and Cretaceous limestone beds (which are subjacent to the tuff platform of the volcano), probably not more than 1,000 m. below sea-level.

5. The fact that the cone of Vesuvius, superposed on Mte. Somma, has been in activity for over 2,000 years and yet only represents one-twentieth of the area and volume of its parent, renders probable its further continuation as an active, centralized volcano. Its paroxysmal eruptions convey an idea of how great must have been the magnitude of the eruptions and the lapse of time to build up Mte. Somma, whose crater was four times larger than that of Vesuvius. Yet even the two combined are not equal in area and magnitude either to the great extinct Lazio volcano near Rome or to the still active giant of Etna in Sicily.

## VI. PETROGRAPHIC NOTE.

### *The Products of Eruption.*

1. *Lavas*.—The leading characteristic of the lavas is the extraordinary uniformity of their composition from the earliest submarine eruptions of Mte. Somma down to the most recent eruptions of Vesuvius. They are all essentially leucite-basanites (augite and olivine with basic plagioclase) and leucite-tephrites (augite, less olivine, and more plagioclase), the latter being more abundant than the former. Within these two eminently basic categories the varieties of colour and texture are determined mainly by the greater or lesser proportion of augite and leucite, by finer or coarser grain, and by compact, porous, or vesicular structure, all of which are governed by the fluidity or viscosity of the lava, by the slowness or rapidity of cooling and crystallization, in short by the conditions of first and second consolidation, the first taking place in the magma before, the second after eruption. The fluid or viscous lava, of a temperature up to 1,000 degrees C., contains most of the crystals of first consolidation already formed; the as yet uncrystallized part of the magma crystallizes to the groundmass in second consolidation.

The lavas exposed in the quarries and other outcrops around the base of the mountain, e.g. at Cisterna on the north, at Caposecchi on the east, at Pompeii, and along the coast, as also the lavas of the great Atrio wall and of the older and more recent lava flows generally

are dark grey in colour. Their predominantly holocrystalline, sometimes also vitreous groundmass exhibits phenos of leucite, augite, olivine, plagioclase (mostly labradorite and anorthite) as constituent, and biotite, apatite, and magnetite as accessory, elements with occasional subordinate sodalite, garnet, and hornblende in cavities. The leucites range from large to pea-size, and are often much altered. The brown vitreous lavas are chaotic masses of scoria, often twisted into cords, wreaths, and cakes or other fantastic forms; in many of the flows and banks the scoriaceous vitreous sheath or crust is conspicuously in evidence. Many of the lavas are superficially covered with incrustations composed of films or layers of salmiac, rock salt, and iron oxide in aggregations of blood-red iron roses, the effect of decomposition and segregation by contact of the lava with gas and steam issuing from fumaroles or from the lava in flow.

The lavas of the most recent eruption of 1906 do not differ from those of all the preceding or earlier eruptions, except that the most recent basanitic lava often contains so much leucite at the expense of plagioclase and olivine as to become leucitite with microliths of plagioclase, augite, and magnetite. In the leucite-tephrites, all the elements of both first and second consolidation, i.e. leucite, augite, and plagioclase (labradorite and anorthite) are very small, with very little olivine. Both categories give proof of very rapid cooling.

2. *Ejected Blocks.*—The blocks of lava ejected during every paroxysmal eruption show the same mineralogical composition as the lava flows, but the ejected blocks of special interest in the Somma-Vesuvian eruptions are those derived from the sedimentary formations, notably from the limestone beds subjacent to the igneous platform. The periods of eruption during which were ejected the largest quantities of blocks and fragments were those following upon early and protracted periods of repose. At that time the Somma crater must have had a funnel-vent of abnormal amplitude for the ejection of massive blocks torn by the explosion from the limestone beds 1,500m. below the summit. The principal ejecta of those periods, as also of several Vesuvian eruptions, are blocks and fragments of old Somma lava, together with innumerable quantities of fragments and blocks of sandstone, and limestone in all forms and stages of metamorphism to marble by contact with the fluid siliceous magma and its steam and gases. The specially interesting feature of these blocks consists in the variety of sublimates of minerals of secondary formation, which crystallized on the surfaces and in the cavities of those ejecta.<sup>1</sup> The minerals, often disposed in zonal aggregations, comprise secondary sanidine, leucite, sodalite, nepheline, hauyne, spinel, garnet, wollastonite, vesuvian, anorthite, mica, hornblende,

<sup>1</sup> These blocks and minerals have been studied more especially by A. Scacchi in his writings, *Atti R. Acc. Napoli*, vol. 1873, 1880, 1881, and by Br. Mierisch, *Auswurfsblöcke Mte. Somma*, *Tschermak's Mitt.*, 1887, p. 113.

olivine, zircon, and others. The ejected blocks appear both as monoliths and as conglomerates formed by cemented fragments. The predominantly dolomitic character of the original limestone lent itself particularly to the process of transformation by the siliceous action of the magma, which, dissolving the carbonate of magnesia, expelled the carbonic acid. It is obvious that, to effect this transformation, the fluid magma must have been in direct contact with the limestone strata both at its seat and in the chimney for protracted periods.

3. *Tuffs and Breccia*.—The enormous banks of these, from 2 up to 50 and 70 m. in thickness, reveal the same composition as the lavas, of which the tuffs are the ashy and pulverized, the breccia the fragmentary, cemented derivatives. The tuffs are generally grey, the breccia, owing to their more earthy cement, more brown in colour, and both contain blocks, pumice, sand, and other ejected material in abundance. The tuffs are of three kinds. The first and principal kind is derived from ash showers, mixed with lapilli and pumice, projected into the air and in their fall forming an ash mantle which is often charged with rainwater and then solidifies as pisolithic (granular, pea, or tear) tuff. The second kind is derived from ash torrents, which during torrential rains furrow the flanks of the ash cone and deposit the material lower down; and the third kind is derived from mud-flows or *lave d'acqua* of previously deposited lavic and tuffaceous material which the streams transport when in flood, these tuffs being therefore of secondary formation. The pumice, which like ash is ejected in enormous quantities, contains micro-crystals of secondary sanidine, augite, and leucite, this last-named mineral being much more frequent in the Vesuvian than in the Somma pumice. The breccia, composed mainly of ejected angular fragments, as distinguished from conglomerates of transported, rolled, and rounded material, are confined more especially to the early Somma eruptions and overlie the old lava flows. One of the largest breccia banks—50 m. in depth—of leucitic lava fragments and pale pumice cemented by volcanic earth and sand is that which separates the Canal Grande from the Pollena ravine.

4. *Mineralogical Composition of Lavas*.—This is summarized in the following table, the only difference between basanite and tephrite being that the former contains less and the latter more plagioclase, and, inversely, the former more and the latter less olivine.

Lavas.	SiO <sub>2</sub> .	Basic Plagioclase.	Augite.	Olivine.	Leucite.	Biotite.	Apatite.	Magnetite.	Sodalite.	Garnet.	Hornblende.
Leucite-Basanite .	47	e	e	e	e	s	a	s	a	a	a
Leucite-Tephrite .	48	e	e	e	e	s	a	s	a	a	a

e = essential.

s = subordinate.

a = accessory.

5. *Chemical Composition of Products of Eruption.*—With the uniformity of the mineralogical composition of the lavas accords strikingly that of their chemical composition, as is shown by the following analyses of lava, scoria, and ash (as tuff material).

<i>Somma-Vesuvius.</i>	(1) <i>Lava.</i>	(2) <i>Lava 1906.</i>	(3) <i>Scoria 1906.</i>	(4) <i>Ash 1906.</i>
	Per cent.	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub> .	47.48	47.89	48.10	48.00
Al <sub>2</sub> O <sub>3</sub> .	18.85	18.49	15.31	16.10
Fe <sub>2</sub> O <sub>3</sub> .	5.24	1.27	3.20	3.35
FeO .	5.12	7.75	5.45	4.90
CaO .	9.51	9.05	12.45	6.53
MgO .	4.40	3.80	7.35	11.35
K <sub>2</sub> O .	6.41	7.15	4.22	3.04
Na <sub>2</sub> O. .	2.65	2.78	1.88	5.26
P <sub>2</sub> O <sub>5</sub> .	0.60	1.66	2.27	1.51
	100.26	99.42	100.23	99.84

The first of these analyses is the mean worked out by Zirkel of fifty analyses of Somma-Vesuvian lavas of different eruptions; the second is the mean of two analyses of the 1906 lava by Pisani; the third, by the same, of lavic scoria, and the fourth, by the same, of ash, both of the 1906 eruption.<sup>1</sup>

## VII. ERUPTIONS OF VESUVIUS (A.D. 79 TO 1923).

xx = Great Plinian Eruptions.      x = Violent Eruptions.

o = Phases of Quiescence.

I Period. 79–1500.	xx xx x xx o	79 204 472 512 685, 993, 1036 1139, 1306, 1500 1500 to 1630	<i>Plinian eruption.</i> Somma crater blown up. Formation of Vesuvius cone. <i>Eruption (Septimius Severus).</i> <i>Plinian eruption.</i> Ashes windblown to Constantinople (Theodosius). <i>Violent eruption.</i> Devastation of district by lava flows and ash showers (Theodosius). Intermittent lava flows. Not well authenticated. Intermittent eruptions and decline of activity. Not well authenticated. <i>Repose</i> 130 years. Somma and Vesuvius clothed with vegetation.
II Period. 1500–1630.	xx	1631	<i>Plinian eruption.</i> Rift on south side of cone. Lava flows on southern and south-western slopes. Ashes windblown to Taranto, etc.
III Period 1631–1906.		1638	Renewed activity.

<sup>1</sup> F. Zirkel, Petrografie, 1894, Leipzig. Pisani's analyses are quoted by V. Sabatini (op. cit.) from A. F. A. Lacroix, C.R. Ac. des Sciences, 2nd July, 1906.

<i>III Period (cont.).</i>		1639 to 1659	<i>Quiescence</i> 20 years.
	x	1660	<i>Violent eruption.</i> New cone formed in Vesuvius crater. Ashes blown to Africa.
		1682	Eruption, increase of new inner cone, overtopping Somma.
		1694, 1698, 1701, 1706	Eruptions of lava flows on south and west of cone.
		1712, 1714 to 1736	Increasing activity, lava flows chiefly on south slopes.
	x	1737	<i>Violent eruption.</i> Radial fracture on south flank. Lava flow to Torre del Greco.
	o	1738 to 1750	<i>Quiescence</i> 12 years.
		1751, 1754, 1755, 1757	Renewed activity. Lava flows on south and south-west.
	x	1760	<i>Violent eruption.</i> Rift of 2 km. above Camaldoli. Lava flow to sea.
		1767	Eruption of lava on north, then south ; fissure between Torre del Greco and Resina.
		1778	Increased activity.
	xx	1794	<i>Plinian eruption.</i> Rift above Torre del Greco. Collapse of inner cone 1660. Lava flow 27 million cubic m.
	o	1795 to 1803	<i>Quiescence</i> 9 years.
		1804 to 1806	Lava flows on both sides of Camaldoli Hill (Torre del Greco).
		1822	Lava flows to Boscotrecase and south-west towards Resina.
		1828 to 1831.	Intermittent activity and eruptions.
	x	1834	<i>Violent eruption.</i> Rift on north side of cone. Lava flow on east to Caposeccle.
	o	1835 to 1849	<i>Intermittent quiescence</i> 15 years.
		1850	Eruption on north side of cone. Lava flow on east, as in 1834.
	x	1855	<i>Violent eruption.</i> Lava flow from west side of cone through Atrio in two arms to Massa and S. Sebaitano, and to S. Giorgio, 17 million cubic m.
		1858	Eruption. Cone dropped 60 m. in height. Lava flow on west.
		1860, 1861, 1867	Lava flows on south and west base of cone.
	xx	1872	<i>Plinian eruption.</i> Cone collapses on north side ; cone in crater becomes pointed, rise to 1,300 m. altitude ; two great lava flows through Atrio to Massa and S. Giorgio ; on south-west Resina.
	o	1873 to 1884	<i>Quiescence</i> 12 years.
		1885	Increasing activity. Fissure on south side of cone with lava flow.
		1891 to 1892	Eruption from fissure on north to south ; lava flowing west through Atrio for two years. Formation of Colle Margherita in Atrio 150 m.
		1893 to 1894	Strombolian eruptions in crater. Lava flow on west.

III Period (cont.).	1895 to 1900	<p>Eruption on south-west side of cone near lower station of wire-rope railway with continuous viscous lava flow. Formation of Colle Umberto in Atrio 100 m., and other lava mound 70 m. in Valle dell' Inferno.</p>
	1904 to 1905	<p>Increased activity ; in 1905 fissure in north-west sector of cone at 1,175 m. altitude with continuous lava flow. Cone, increased by feeble eruptions of lapilli rises to 1,330 m., its maximum height since 1872.</p>
IV Period (present).	xx	<p>1906</p> <p><i>Plinian eruption.</i> Collapse and lowering of cone by 80 m. to 1,250 m. altitude. Two great Plinian explosions with heavy ash showers. Three great lava flows 6 million cubic m. (1) towards Terzigno ; (2) and (3) to Boscorecace from rifts on south base of cone. Eruption lasted four days.</p>
	o	<p>1907 to 1923</p> <p>Quiescence 12 years, then feeble activity in crater ; in 1920, 1921, 1922, and 1923 greater activity by strombolian eruptions in crater.</p>

X.  
**Etna.**

- I INTRODUCTORY.
- II GENERAL GEOLOGICAL FEATURES.
- III THE ANCIENT ETNEAN BAY.
- IV PRE-ETNEAN SUBMARINE ACTIVITY.
- V THE VOLCANIC EDIFICE OF ETNA.
- VI HYDROGRAPHIC CONDITIONS.
- VII RADIAL FISSURES AND LATERAL CRATERS.
- VIII PREHISTORIC LAVA FLOWS.
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- X CENTRAL CONE AND APPROACHES.
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- XIV LIST OF RECORDED ERUPTIONS.
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ILLUSTRATIONS, FIGS. 14, 15.

I. INTRODUCTORY.

THE great Sicilian volcano, with its snow-capped summit rising to 3,300 m. (10,600 ft.) from the shores of the Ionian Sea, dominates, like a mighty white beacon, not only the whole island of Sicily and the opposite coast of Calabria, but the Mediterranean all round, the mountain being visible even from Malta. Unlike the Neapolitan volcanoes, notably Vesuvius, the Phlegræan Fields, and Epomeo of Ischia, whose records of the pre-Christian era are uncertain, Etna, lying in the path of the early navigators and traders of the near East,<sup>1</sup> figures prominently in the writings of ancient Greece and later also of ancient Rome. The earliest record occurs in Homer about 800 B.C. in reference to the huge volcanic missiles hurled at Ulysses by the roaring, one-eyed giant Polyphemus, this giant being Etna itself and his eye the summit crater in explosive eruption.<sup>2</sup> Pindar (522–448 B.C.), while at Syracuse, extolled the

<sup>1</sup> The Greek and Phœnician traders found the east coast of Sicily in the possession of the Sicilians, a race of Lucanian origin, immigrated from Calabria. These were preceded, probably 2000 to 1000 B.C., by the Sikilians, a Celto-Basque race who crossed from the Pyrenees to Corsica, Sardinia, and Sicily. According to Pindar and Thucydides, they were driven from the east coast to the west of the island by the ravages of the Etnean eruptions. Their place was taken by the Sicilians, who became the dominant race. Since then, the successive invasions of no less than ten different Eastern, African, and European races in the course of 3,000 years have produced a curious mixture and blending of the island's population which lives under the shadow of Etna.

<sup>2</sup> Similarly, the legendary battles which, according to the tradition quoted by Thucydides, raged on the mountain between Cyclops and other giants, were simply the volcanic phenomena and the battles of the elements.

great volcano as the " sucker of snow and the pillar of heaven ". Thucydides (470–404 B.C.) mentions an eruption of 693 B.C. and two great eruptions during his stay in Sicily ; Livy (59 B.C.–A.D. 17) records three in the second and first centuries B.C., and Strabo (60–20 B.C.) graphically describes the summit crater and the little town of Aetna on the western flank whence the mountain was usually ascended. Diodorus, Strabo's contemporary, (60 B.C.) also records several eruptions ; the Latin poets Ovid (43 B.C.–A.D. 19) and Virgil (70 B.C.–A.D. 19) sang the praises of the great volcano, and the Emperor Hadrian ascended it on his return from the east during his travels from A.D. 120 to 135. Several still later eruptions are mentioned by Orosius the historian, writing in A.D. 417. After the fall of Rome and during the dark ages, when Sicily became the prey of the invasions of Vandals and Saracens, there is a total absence of records of Etna as a volcano, and it was not till the conquest of the island by the Normans under Roger I in the eleventh century that the history of the mountain's activity was resumed. Scientific interest in the eruptions dates, however, only from the volcanic outbreaks in 1536 and 1537 described by Fazellus,<sup>1</sup> and still more from the paroxysmal and disastrous eruption of 1669 described by G. A. Borelli (1670).<sup>2</sup> Further reference to all these eruptions will be made in the sequel.

Among outstanding comprehensive works on Etna since 1670 may be mentioned more especially G. Recupero's history of Etna<sup>3</sup> (1815) ; Sartorius v. Waltershausen's monumental work including a comprehensive trigonometrical and geological survey, completed and edited after his death by A. v. Lasaulx (1880)<sup>4</sup> ; the lifelong studies of Mario Gemmellaro and his brothers Carlo and Gaetano<sup>5</sup> ; O. Silvestri's accounts of the eruptions of 1865 and 1879,<sup>6</sup> and G. Ponte's, G. Platania's, and A. Ricco's, as also V. Sabatini's descriptions. Of the eruptions of 1910 and 1911<sup>7</sup> the bibliography of

<sup>1</sup> T. Fazellus, *De Aetna Monte (De Rebus Siculis)*, 1558 ; in Italian, 1628.

<sup>2</sup> G. A. Borelli, *Historia Incendii Aetnae*, 1669, published 1670.

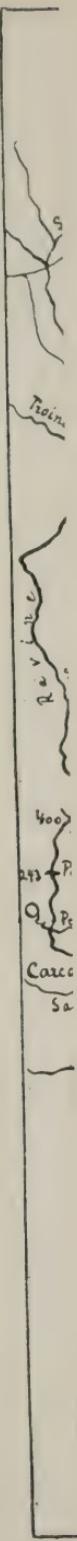
<sup>3</sup> G. Recupero, *Storia naturale e generale dell' Etna*, edited by his nephew, A. Recupero, 1815.

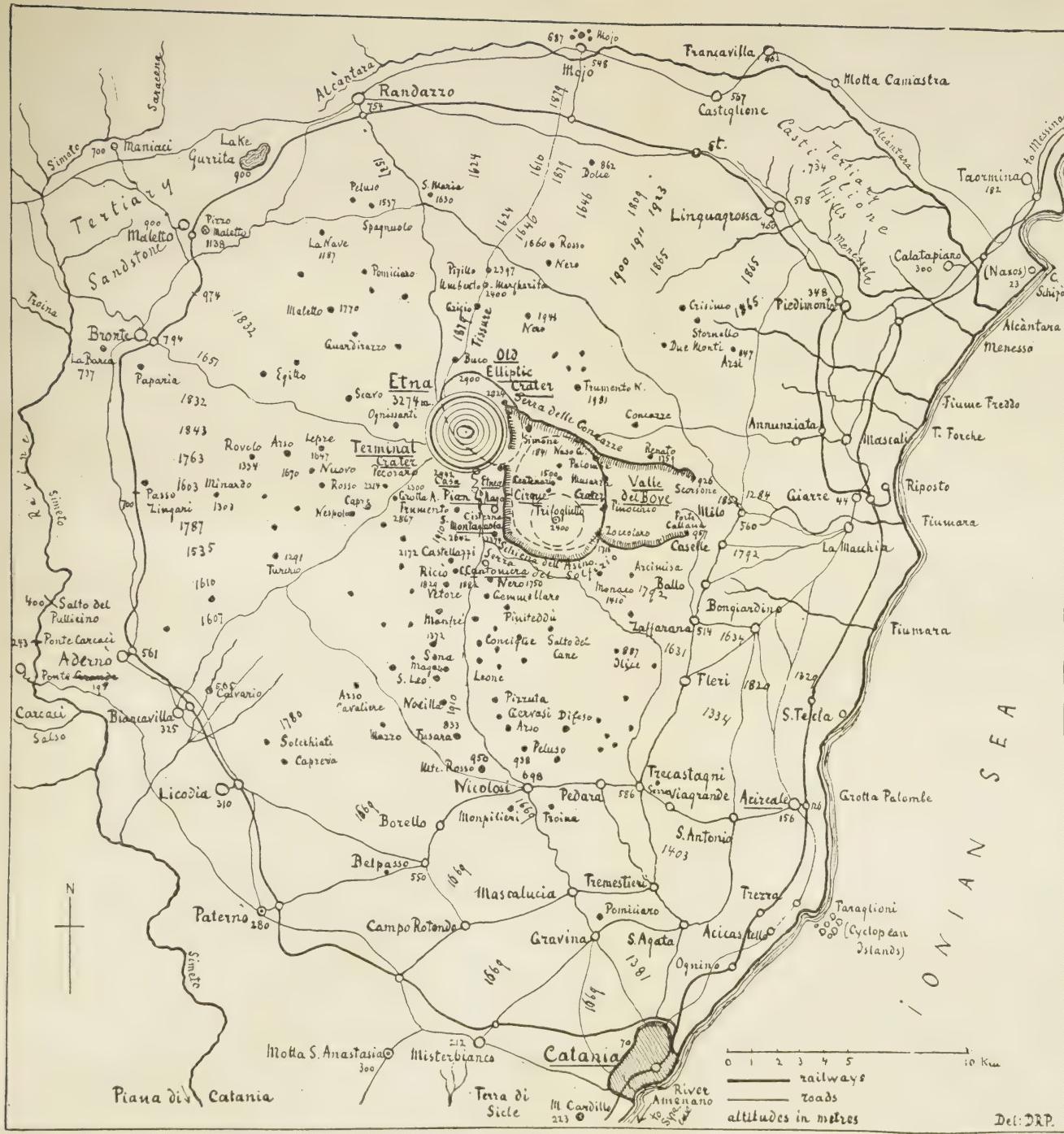
<sup>4</sup> W. Sartorius v. Waltershausen, *Der Aetna, Atlas*, 1848, and complete work, two volumes, edited by A. v. Lasaulx, 1880.

<sup>5</sup> Mario Gemmellaro, of Nicolosi, life-long naturalist and explorer of Etna (writings 1809–53). His brother, Carlo Gemmellaro, Professor of Geology, University, Catania (writings 1819–66) ; *Vulcanologia dell' Etna*, 1858. *Descriptions of Eruptions (7)*, 1819 to 1832.

<sup>6</sup> Orazio Silvestri, Professor University, Catania, 1864–90. *Eruzione dell' Etna*, 1865. *Atti Sc. Ital. Milano*, 1866. *Doppia Eruzione* 1879, Catania 1879.

<sup>7</sup> G. Ponte, *Eruzione Etnea*, 1910 ; *Atti R. Acc. Lincei Roma*, 1911. G. Platania, *Eruzione*, 1910 and 1911 ; *Riv. Geog. It. Firenze*, 1910 and 1912. A. Ricco, ditto, *C.R. Ac. Sciences, Paris*, 1910. Modena, 1911. V. Sabatini, *Eruzione dell' Etna*, 1910 ; *Boll. R. Com. Geol. It.*, 1910. The first three of these are the present Etnean specialists of the University of Catania. Professor Ricco is also director of the Etnean Observatory.





Etna down to the present time<sup>1</sup> comprises, not indeed as many writings as that on the more generally known Vesuvius, but still at least 700 publications, to which every new eruption adds its quota.

## II. GENERAL GEOLOGICAL FEATURES.

Etna, or its Arabic synonym Gibello Utlamat, italicized to Mongibello, the "burning mountain", with the city of Catania at its southern base, lies about midway between Messina and Syracuse in a great Pliocene subsidence bay of the Ionian Sea, similar to the bays of Gaeta, Naples, Salerno, Policastro, and the Lipari Islands in the Tyrrhenian Sea. The Calabrian Apennine formations of Eocene macigno sandstone, Miocene albarese limestone and molasse, and Pliocene marine marl, clay and conglomerate, overlain by Quaternary gravel and sand deposits, are also the principal components of Eastern Sicily as the extension of the Calabrian Peninsula, later separated by a shallow subsidence which produced the Straits of Messina. Only the north-eastern extremity of the island, i.e. the Peloritani range of hills immediately north of Etna and north-west of Messina, belongs to an older Permian formation of gneissic schists and granitic rocks, which is also an extension of the corresponding formation of the Calabrian coast. It constitutes the substratum of all the more recent formations, including some Jurassic bands and banks at and near Taormina, and it is this transgressive, often unconformable superposition of those as yet insufficiently settled Jurassic and Tertiary formations on a much older, rigid platform that is the main cause of frequent earth movements and consequent disastrous earthquakes such as those on both sides of the Straits of Messina and the Ionian Sea, as well as in Sicily generally. These earth-shocks, including the great catastrophe of Messina and Reggio of 1908, are of purely sedimentary origin, and have no connexion with the volcanic earth-shocks of Etna, just as the eruptions of the latter are quite independent of those of Vesuvius and the older Neapolitan volcanoes, and even of those of the Lipari Islands (Stromboli and Vulcano), 25 km. north of the Sicilian coast.

## III. THE ANCIENT ETNEAN BAY AND PLATFORM.

As a volcano, Etna occupies an altogether unique, isolated, and self-contained position. In its altitude of 3,300 m. it is not only the highest volcano in Europe, but also the highest mountain of Southern Italy, exceeding Vesuvius (1,200 m.) by more than 2,000 m., and even Gran Sasso d'Italia (2,930 m.) by over 350 m. Its roughly elliptic base, whose major axis is 50 km. and its minor axis 30 km., covers an area of 1,200 sq. km. or six times larger than that of Vesuvius. It is sharply circumscribed on the east by the Ionian Sea, on the north by the River Alcántara, and on the west and south

<sup>1</sup> H. J. Johnston-Lavis, posthumous Bibliography S. It. Volcanoes, 1918.

by the River Simeto, the largest river of Sicily. Only in the north-west sector, i.e. on the Maletto divide or saddle 8 km. in length between those two rivers, is the volcano in contact with the inland Tertiary sedimentary formations already referred to.

These sedimentary formations, rising to about 1,000 and 1,500 m. altitude, constitute the outside border of the two rivers, and therefore a complete, roughly semicircular belt round the land side of the volcano, which thus towers no less than 1,800 to 2,300 m. above them. The sedimentary belt marks in fact the periphery of the ancient Etnean gulf, 50 by 30 km., the inner circle of which is now occupied by the volcano. The grey Eocene and the yellow and reddish Miocene sandstone and limestone banks slope from the Maletto saddle down into the ancient bay and dip below the Pliocene marine marl and plastic clay, which entirely composes the floor. This fossiliferous marine formation, called "creta", grey to blue and yellow in colour, rises to over 200 m. above sea-level and thus, together with the Tertiary sand and limestone projecting into the ancient bay, constitutes the platform of the volcano. Along the coast the Pliocene creta is overlain by Pleistocene subaerial conglomerates and gravels with more recently superposed alluvial deposits. All these sedimentary formations crop out in various places around the base of the volcano, forming islands or "dagale" among the lava flows and tuff banks. The early Quaternary uprise of the sandstone formation and of the Pliocene marine creta, not only in the Etnean Bay but in the rest of Sicily, must have been considerable, for Pliocene deposits in places overlie the hills of the sandstone belt and Pleistocene gravels, and conglomerates are met with in the Tertiary hills of the Alcantara valley up to 500 and even 1,000 m. altitude, as they are also in the Apennines.

As regards the Etnean bay itself, the altitude of 1,000 m. of the Maletto sandstone saddle between the rivers Simeto and Alcantara marks the maximum elevation of that formation within the bay. As previously mentioned, the volcano abuts against the inner seaward slope of the sandstone beds, which at an angle of 45 degrees probably do not extend more than 1 km. into the bay and then dip below the Pliocene creta, upon which the mountain is built up to a height of over 3,000 m. Sedimentary fragments ejected by the summit crater show that the central chimney passes through sandstone strata and the overlying creta. The important fact that ancient lava flows near the coast overlie the Pleistocene conglomerates and gravels affords proof of the subaerial volcanic activity of Etna having begun at a relatively recent period, i.e. not till middle Quaternary times.

#### IV. THE PRE-ETNEAN SUBMARINE PHASE OF VOLCANIC ACTIVITY.

From Catania northwards along the coast to Aci Reale, and southwards to Lentini, Palagonia, the Valle di Noto and Mte. Lauro south and west of Syracuse, in a total length of 100 km., extends

an intermittent series of bosses and masses of ancient basalt disposed on a fissure which in the north fringes the mouth of the ancient Etnean bay and in the south runs, as a continuation of the former coast-line, about 30 km. inland from the present bays of Augusta and Syracuse. Within the Etnean bay these basalt masses with their tuffs emerge from the Pliocene creta through which they were injected by submarine eruptions during the submergence of the bay, and later, i.e. in Pleistocene times, raised with the creta above sea-level. The two largest basalt masses, 10 and 20 km. west of Catania, are respectively those of Motta St. Anastasia and the Rock of Paternò, the former a precipitous cliff 50 m. high (300 m. altitude), built up of two great basalt columns with a mass of basalt and tuff between them, surmounted by an ancient church; the latter a similar mass of similar height, rising out of the creta plain of Paternò and surmounted by a Norman tower. The columnar basalt bosses north of Catania constitute within a distance of 10 km. a chain or fringe in the sea close to the shore, the most notable ones being those of Aci Castello and the Cyclopean islands or Faraglioni near Trezza, not unlike the columnar basalt bosses of Staffa etc., on the west coast of Scotland. They owe their grotesque ruin-like forms to the wearing action of the sea which, in 1862, destroyed among others the remarkable "arco naturale" close to the shore in front of the terrace of Aci Reale. Some of these basalt masses rest on tuff, showing that the submarine eruptions were accompanied by ejections of ash showers; others are simply composed of viscous lava forced up from the fissure through the submarine creta. They are in fact the submarine equivalents of the "bocche" or lava mounds which are so conspicuous a characteristic of the subaerial fissural eruptions of Etna. They have no connexion with the latter; but it is probable that during the gradual uprise of the creta platform from the ancient Etnean bay, when the latter was still partly submerged, fissures formed also in that semicircular floor and gave rise to initial volcanic phenomena similar to those of the Phlegræan Fields, Roccamonfina, Vulture, and Mte. Somma. It is a noteworthy feature that the Pleistocene conglomerates and gravels of the coast contain in their upper layers fragments of those ancient basalts, which points to the latter being older than the former and *à fortiori* considerably older than the earliest subaerial activity of Etna proper. The petrographic properties of these ancient submarine basalt masses will be dealt with in the sequel (XV).

## V. THE VOLCANIC EDIFICE OF ETNA.

Considered as a huge pyramid, Etna may be described as being built up of three superposed parts: (1) the lowest part, from the base at sea-level (Catania) to 2,000 m. altitude, which, rising gently in a distance of 23 km. at a mean gradient of 1 in 90, constitutes a great belt or mantle of volcanic products around the central cone, abutting against the latter at the altitude mentioned; (2) the central

cone, rising from that point of contact to the Pian del Lago plateau at 2,950 m. altitude in a distance of 5 km., equal to about 1 in 5 ; and (3) the superposed terminal, central ash cone which rises from the Pian del Lago plateau to the rim of the summit crater at 3,274 m. altitude in a distance of 2 km. at the rate of 1 in 6.

The total distance of 30 km. and the rise of roughly 3,300 m. from the southern or most extended base comprises, in respect of the distribution of volcanic products, three consecutive regions : (a) the lowest, up to 1,000 m. altitude and 16 km. in width, composed mainly of superposed lava- and ashfields reduced to cultivation ; (b) the middle, from 1,000 to 2,000 m. altitude, comprising in a belt of 8 km. in width, the greater part of the 200 lateral cones and craters of Etna ; and (c) the upper region, from 2,000 m. to 3,300 m. altitude in a width of 6 km., comprising the barren lava and ashfields of the central and terminal cones.

To these three regions correspond approximately the three belts of cultivation, locally known respectively as the *regione coltivata*, densely populated and of luxuriant fertility in vine, fruit, olive, vegetables and corn, yielding as many as five harvests in the year ; the *regione boscosa*, now largely depleted of its magnificent old oak plantations, but still rich in chestnut, pine, beech, genista broom, and ferns ; and the *regione deserta* of the central cone, a chaotic accumulation of lava and ashfields destitute of vegetation. On the western and northern flanks of the mountain, the distance from the base of the summit is only 12 and 15 km. respectively. The Maletto sedimentary divide of the rivers Simeto and Alcàntara at 1,000 m. altitude lies already in the *regione boscosa* and is alpine in character. On the northern flank the *regione coltivata* is restricted to a few km. in width, while the north-eastern flank, in part as yet well wooded, marks the transition from the subalpine to the subtropical conditions of the eastern and southern slopes bordering on the sea.

The east flank of Etna presents the feature, unique among the volcanoes of Europe, of the great rift of the Valle del Bove which, as will be shown in the sequel, was the seat of an enormous centre of eruption before the eruptive axis shifted to the present summit crater.

## VI. HYDROGRAPHIC CONDITIONS.

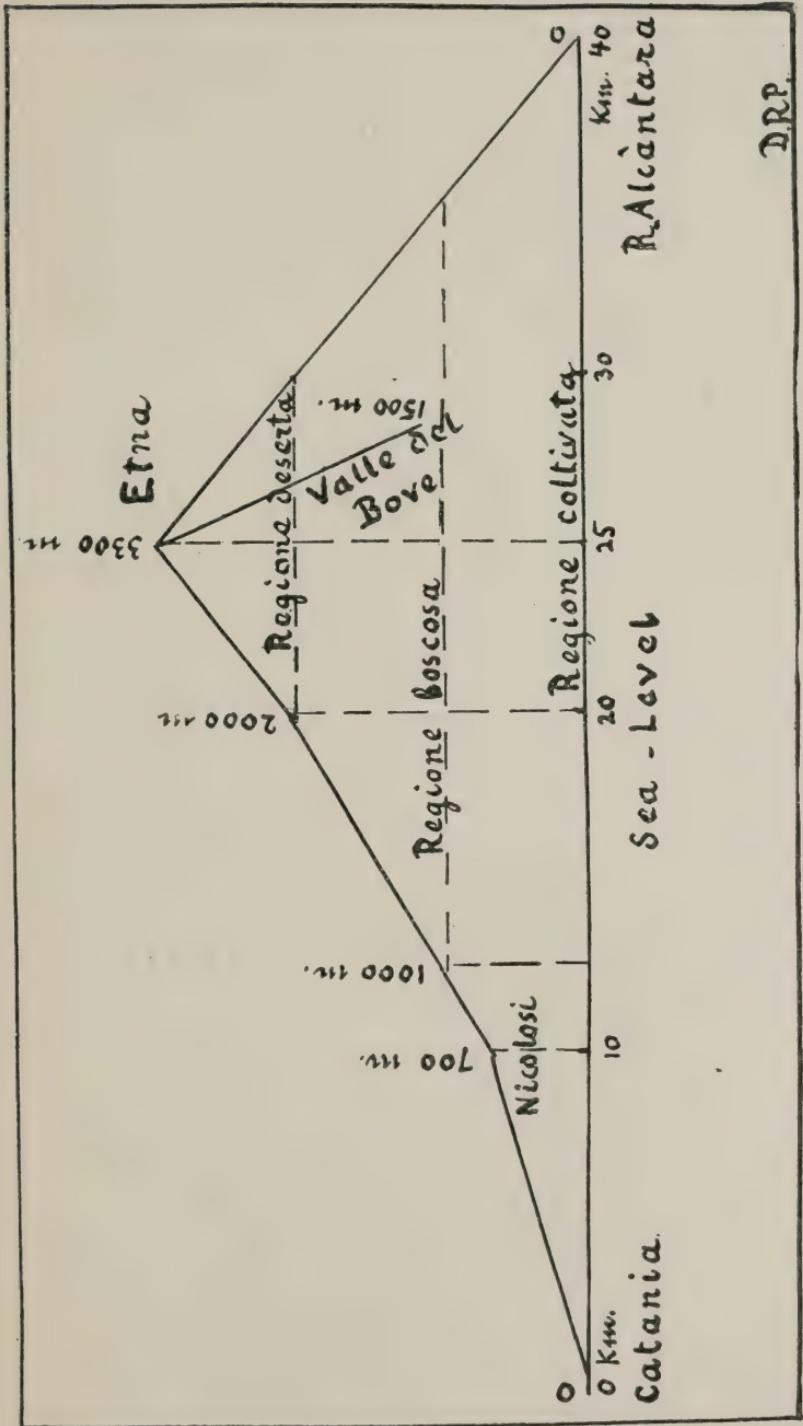
In contrast to Vesuvius, whose base or cultivated area is irrigated by the streams descending by the radial ravines or valloni, Etna is virtually destitute of perennial streams, all the atmospheric moisture and precipitation being at once absorbed by the permeable volcanic surface soil and the countless underlying lava flows all round the mountain. The rivers Simeto and Alcàntara, which encircle Etna on three sides, receive practically no feeders from the mountain, and it is only on their sedimentary banks outside Etna that a number of affluents drain into them. The innumerable gullies, i.e. the so-called *fiumare*, which furrow the mountain sides all round as cracks in the lava- and ashfields, are ordinarily dry and carry volcanic mud-flows only for a few hours after torrential rains or the sudden

Sketch-Section of Etna.

Fig. 15.

Etna.

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N.B.—The altitudes in the above section are on a scale four times larger than that of the distances, so as to show the division of the three “regions” on the eastern flank of the mountain. The actual distances of the section south to north are given in the text, p. 130.

melting of the snow-cap of the summit. On the upper slopes from 1,000 m. upwards the only supply of water for domestic and agricultural purposes is derived from carefully tended pits or cisterns. Several of these lie in the path of descending lava flows, and when, as has repeatedly happened, a red-hot lava flow plunges into a cistern, a huge explosion follows like the opening of a new crater. These explosions in the open convey an idea of the stupendous paroxysmal violence of the underground contact of the fluid magma with water, steam, or gas producing earth-shocks which shake and rend the whole volcanic edifice.

Of the snow and rain-water which the volcano voraciously absorbs like a huge filter, only a relatively small part emerges at the contact of the lava flows with the underlying impermeable creta at about 200 m. altitude. It is at this and lower levels of the cultivated slopes that issue a number of excellent, copious, and, in part, mineral springs sedulously tended for irrigating three gradations of soil : the *terra vergine*, i.e. the lava-girt plots or *dagale* of creta and gravel, i.e. non-volcanic soil, the *terra forte* and the *terra leggiera*, i.e. the heavier and the lighter soil of disintegrated and therefore fertile lava and volcanic ash mixed with alluvia.

Soaring to a height of 3,300 m. in solitary grandeur, Etna not only acts as a potent absorbent of atmospheric precipitation, but is also the meeting place and battle ground of equatorial and polar currents. Hence it is at all times subject to high winds and violent atmospheric phenomena. Its great snow-cap, with small glaciers forming in severe winters on the summit crater walls, extends usually down to 2,000 m. altitude ; in spring it generally shrinks towards the summit, which only in July and August is free of snow. The latter, being in the condition of nevé, collects in sheltered hollows and pits, called *tacche di neve*, where it is carefully covered with volcanic ash and brushwood for use in Catania and other Sicilian towns as a substitute for ice in summer.

On the east coast, the only more or less perennial rivers of inconsiderable length and rising at the contact of lava, or tuff with the creta, or in the latter alone, are the Menessala, Freddo, and Forche in the northern part, the Acis, only 1 km. in length, at Aci Reale, and the Amenano, barely 500 m. in length, which rises in the city of Catania and will be referred to in the sequel. All round the volcanic flanks of Etna the only notable watercourses are the fiumara of Biancavilla, on the south-west flank, 10 km. in length, and that of Linguagrossa on the north flank, neither of them perennial. The annual rainfall on the slopes of Etna is about the same as on Vesuvius, 800 mm. (32 inches).

## VII. THE RADIAL FISSURES AND LATERAL CRATERS.

Unlike Vesuvius, which is a single volcanic unit, Etna is essentially a great polygenous volcano which, besides its central chimney, cone, and crater, is studded all round its flanks and more especially

in its middle section between 1,000 and 2,000 m. altitude, with upwards of 200 parasitic or lateral cones and craters of explosive origin, i.e. built up of ash, lapilli, and scoria. In addition to these, over 800 mounds or "bocche" are piled up by the effusion of lava during eruptions. The great feature of all these parasitic cones and mounds of volcanic products consists in their having been formed, not independently of, but in direct connexion with the action of the central crater. The connecting link between an eruption—more generally an explosion—of the central crater and the simultaneous formation of one or more explosive lateral cones and effusive bocche is always a radial rent or fissure which bursts open under the explosive pressure of gas and steam imprisoned in the central chimney. These fissures always converge towards, or run radially downwards from, the central cone and crater. In the majority of eruptions the central crater acts now mainly as a safety valve of the umbrella or pine clouds of ash and other explosive, pulverized material, while the fluid magma finds lower and more easy outlets through the fissural ramifications of the trunk chimney.

The lava exhibits a marked tendency to follow previously formed fissures till it reaches a point where such fissures have been plugged by former lava flows. The new lava, issuing at a temperature of 1,000 to 1,500 degrees C., then either overflows and continues its downward course on the surface, or, if in a viscous state, forms mounds or bocche of lava on the fissure. In some cases the lava issues at the highest point of a fissure; in others it issues at the lowest point, and, if impeded in its flow, is banked and runs up the fissure. In either case, if the lava is charged with imprisoned gas and steam, an explosion accompanies its issue from the fissure, and a parasitic cone, often with twin craters, is piled up of the pulverized material, i.e. ash, lapilli, and scoria. The lava then flows from these twin craters and soon forms a midway outlet channel for both, hence the cone often assumes a double-peaked or horned form with a connecting ridge or depression between those points. The lateral cones, some isolated, others in groups, but most of them aligned in radial rows during one or more eruptions on the same fissure, vary in height up to 300 m.; the lava mounds or bocche, on the other hand, are much lower and are often disposed on a fissure in series up to twenty and thirty in number. Some of the most remarkable lateral craters will be mentioned later.

Striking evidence of the correlation of fissures to lateral craters is afforded by the so-called "Grotte", i.e. subterranean caves, vaults, and passages from 7 to 20 m. high, and up to 7 m. wide, through which the lava passed upwards into the funnel of the crater superposed on the fissure. Notable among these fissures are Grotta delle Palombe and Grotta lunga, 2 km. north-west and north-east of Nicolosi, Grotta degli Archi, 5 km. south-west of the summit of Etna, towards Adernò, and the fissure 3 km. long and 7 m. wide of Cefalo, near Mascalucia, 8 km. north of Catania.

The earth-shocks which almost invariably herald the actual eruptions are caused by internal explosions, by the breaking of the fluid magma through the successive rock strata, and by the pressure in the chimney and on the fissures along which the magma passes in its upward course. In the older historic eruptions lava was often vomited simultaneously by the central crater and the radial fissures or the parasitic craters; but, as in the case of Vesuvius, the lava column in the central chimney now rarely rises to the rim or even to the floor of the central or summit crater and finds its outlet laterally at lower levels. The fissures and lateral craters thus act more and more in relief of the central crater.

In the long course of its prehistoric and historic paroxysms the mountain has been furrowed by countless radial fissures filled, plugged, and covered by the volcanic products of successive eruptions, as is strikingly revealed more especially in the great cirque of Valle del Bove on the east flank of the mountain, to be described later. Besides that stupendous eastern rift, there is evidence of the mountain having been rent at a relatively early period of its activity on the north-west flank by a fissure which extended to the lateral crater of Mte. La Barca, near Bronté; on the north flank by a fissure reaching to the craters of Mojo; and on the south flank by the long fissure of Cefalo and the Pomiciaro crater above Catania, all in direct or indirect connexion with the central crater and marking the extreme points of volcanic activity from the latter at distances of 15 to 20 km. As a rule, the fissures of great eruptions vary from 2 to 6 m. in width and up to 10 km. in length, one of the most recent being the phenomenal fissure of the eruption of 1879, which, running south to north, rent the whole central cone in twain. The cause of these paroxysmally formed fissures which constitute so characteristic a phenomenon of Etna, quite different from the superficial, radial valloni of Vesuvius, more or less eroded and widened into ravines by water and atmospheric agency, must be sought both in the enormous bulk of the mountain and in the stupendous explosive forces at work in the magmatic reservoir to find an outlet for the gases, steam, and the huge volumes of fluid lava through the great central chimney and its ramifications.

### VIII. THE PREHISTORIC LAVA FLOWS AND TERRACES.

As will appear in the Petrographic Note at the end of this paper, the lavas and corresponding tuffs of Etna, juxtaposed and superposed in countless sheets and banks on the sedimentary platform, exhibit, on the whole, remarkable uniformity of chemical and mineralogical composition, showing that the magma of essentially low basicity has in the course of ages undergone relatively little change. The difference between the older and the more recent basaltic, all plagioclastic and non-leucitic lavas lies in their stratigraphical and petrological characteristics which determine their age.

Notably, as regards the degree of their adaptability to cultivation, the difference lies between lavas with potash etc., viz. fertilizing alkali, which easily yield to disintegration, and lavas of dominantly scoriaceous, porous, and vitreous, i.e. unproductive, character. The former often become productive within the relatively short period of fifty years after their deposition; the latter, known as *sciarra viva*, or raw lava, often remain for centuries, or even permanently, sterile. This is notably the case in the waterless Valle del Bove, as well as on the colder north-west flank and even in some of the old lava flows on the highly favoured western and eastern slopes of the mountain.

Next to the pre-Etnean basalt fringe along the coast, the oldest eruptive products of Etna proper are the great banks, dykes, and veins of augitic-andesitic lava which constitute the outstanding feature of the upper Valle del Bove as the oldest seat of subaerial volcanic activity of the mountain. An exact equivalent of these more acid lavas is the isolated lava boss of Mte. Calvario, near Biancavilla on the south flank, north-west of Catania, probably the remnant of a larger, now buried area.

Next in the order of old lava flows figure the great terraces of superposed banks on the western base of the mountain, near Bronté, overhanging the defile of the River Simeto, and similar terraces are in evidence along the River Alcantara on the northern base. In both localities the old lava flows invaded and blocked the beds of the two rivers, expanding along the banks or beyond. Both the Mte. La Barca crater near Bronté, above the Simeto on the west, and the Mojo craters above the Alcantara on the north, are among the earliest of Etna.

To the early eruptive formations belong also the lowest lava flows overlying the creta substratum in the city of Catania and the lava terraces along the coast, more especially the famous terrace of Aci Reale, crowned near the southern end by the city of that name,<sup>1</sup> 12 km. north of Catania. This terrace, 7 km. in total length, runs close along the coast, and in its highest part, about midway, rises in a length of 3 km. to 150 m. above sea-level, the steep, partly vine-clad slope having an angle of 45 degrees. In this section the terrace exhibits no less than eight superposed bands of basaltic lava from 2 to 12 m. in thickness, separated from each other by as many layers of tuff, including a bank 40 m. thick. The sequence thus represents one or more phases of eight successive eruptions. Of these layers the lower five, up to 107 m. above sea-level, are, however, of submarine origin,<sup>2</sup> as is shown by the presence of marine shells in the tuff layers. These five bands were, like the probably contemporaneous coastal

<sup>1</sup> Aci Reale was almost entirely rebuilt after the great earthquake of 1693.

<sup>2</sup> Recupero (op. cit.) regarded the tuff banks of Aci Reale as vegetable earth, i.e. as inter-eruptive deposits. The marine shells in them and their petrological correlation to the lava banks showed them, however, to be of submarine origin as first recognized by Sartorius v. W.

basalt fringe previously referred to, raised with the coast, while the upper bands were deposited on them as the products of early sub-aerial eruptions of Etna proper. The well-known Grotta delle Palombe at the base of the terrace of Aci Reale is not an eruptive fissure but a cave, 10 m. high, of layers of tuff with superposed columnar basalt, not unlike Fingal's Cave on the west coast of Scotland.

The great expanses of lava- and ash-fields which the lateral craters, in conjunction with the central vent piled up on the mountain in historic times, may best be studied by examining (1) the peripheral base of the volcano and its surroundings; (2) the south flank—as the most instructive—from Catania to Nicolosi and the summit-cone and crater; and (3) the great cirque of Valle del Bove, as the earliest seat of subaerial eruption, followed by various great eruptions in historic times.

#### IX. THE HISTORIC LAVA FLOWS AROUND THE PERIPHERAL BASE.

The study of the roughly elliptic base of Etna has been greatly facilitated since the construction of the circum-Etnean railway. Like the more or less contiguous circular high road, it skirts the margin of the lava, tuff, and ash terraces which slope down to, or overhang, the river-beds, from 5 to 2 km. distant, of the Simeto on the west and of the Alcantara on the north. In its total length of 113 km. (70 miles), from Catania up to the Maletto sedimentary divide at 974 m. altitude, and thence down to the coast at Giarre, the line rises and falls respectively at a mean grade of 16 m. per km. or 1 in 60. The coastal section of 30 km. from Giarre to Catania, which forms part of the littoral main line from Messina to Catania and Syracuse, completes the inner circle, i.e. the terraced base of the mountain, in a total length of 143 km. (88 miles), while the outer circle, which is bounded by the rivers Simeto and Alcantara, measures 160 km. or 100 miles. The redundant population of the twenty towns and numerous villages around the periphery, 350,000 in an area of 700 sq. km., is equal to 500 per sq. km. (1,250 per sq. mile); on the southern and eastern slopes it is more than double that density, and vies with that around Vesuvius.

*In and around Catania.*—Second in population and importance only to Palermo, the city of Catania, founded by Greek settlers in 729 B.C. and several times rebuilt, rises on the gentle slopes of the southern base of Etna. It lies in a bay of its own, towards which converge in juxtaposition no less than ten lava flows overlying the substratum of creta, gravel, and tuffs of ash and scoria. Of these ten flows the lowest six, directly resting on that substratum, are prehistoric, including the great lava field of Larmisi in the northern part of the city. The other four lava flows are the historic ones known as the Carvana (122 B.C.), the Cefali (A.D. 252), the Crocifisso (1381), all these in the northern area, and the huge flow of 1669, which occupied the whole southern part of the city and

plunged into the sea, piling up a black cliff in the old harbour. In addition to these disastrous invasions, the city was partially destroyed by the great Sicilian earthquakes, of sedimentary or submarine, not volcanic origin, of 1169 and 1693, after which last-named it was in great part rebuilt for the third time. With the great lava flow of A.D. 252 is intimately associated the tradition of St. Agatha's—the city's patron saint's—veil as stemming or deflecting the tide of lava flows on their approaching the city.

As early as the advent of Roman dominion, in the second century B.C., Catania drew its water supply from the copious springs of the creta and gravel hills or *dagala* of Cefali, Licatia, and St. Paolo, encircled by lava flows north of the city, and, further, from the springs of Licodia, 25 km. north-west by the still existing aqueduct of Marcellus (210 B.C.). A special feature of Catania is the much-debated River Amenano which, as previously mentioned, rises in the city itself and discharges into the sea, partly under vaulted cover, after a course of barely 500 m. It issues from a fissure in the lowest and oldest prehistoric lava flow of the city, i.e. below the ancient Greek, later Roman theatre, and rises from the creta substratum of that lava. The tradition of the river being mysteriously connected with the marshy lake of Gurrita on the north-west flank of Etna, 45 km. distant, as also the theory, favoured by Lyell, of its having been the eroding agency of Valle del Bove, 25 km. distant, are alike without foundation.

About 5 km. west of Catania extends a curious, roughly circular area, 4 km. in diameter, of barren, much broken creta hills, which slope south to the extensive delta of the Simeto and its large affluent the Dittaino. The creta area—a former island—is known as "Terra di Siele", the Simeto delta as "Piana di Catania". This, the largest plain of its kind in Sicily, is entirely composed of terra forte, i.e. of rich marly soil and the alluvia of the Simeto charged with productive volcanic ash and disintegrated lava. The phenomenal fertility of this plain makes it, apart from the abundant cultivation of vine, the granary of Catania. It connects with that city by the hilly coastal strip of Mte. Cardillo (223 m.).

*Catania-Paterno-Adernò*, 39 km.—From Catania to the town of Misterbianco (212 m. altitude) the railway traverses the great lava field of 1669, which covers the whole southern slope from Monte Rosso (its source near Nicolosi) to Catania, Misterbianco, and Campo Rotondo, a triangle of 16 km. each side. Like Catania, Misterbianco was rebuilt after that disaster, and the same applies to the village of Belpasso, higher up at 550 m. altitude. West of Misterbianco, at a distance of 4 km., rises out of the creta the Motta St. Anastasia basalt cliff, previously referred to, and 12 km. north-west from the same point, on a low terrace 5 km. from the Simeto, lies the town of Paternò (280 m. altitude), in which rises the similar basalt boss already mentioned. Above that town, and below Belpasso, issue the much discussed, so-called "salinelle", "maccalubi", or mud-

volcanoes, a cluster of thermal springs of 35 degrees C., which spasmodically bubble, overflow, and, charged with mud, spread their ejecta on the surface around. They have no connexion with Etna as a volcano, but are in origin and action similar to the salinelle of Val di Noto, west of Syracuse.

From Paternò the line runs to Licodia and Biancavilla (352 m. altitude) along the lava field of 1169, which issued from the lateral crater Mte. Sona (1,372 m.). On the right it passes the old andesitic lava hill of Mte. Calvario (565 m.) previously mentioned, cut into two parts by the fiumara of Biancavilla; and on the left, below that town, the scoria, tuff, and columnar basalt cave "Grotta di Scilla". Both Biancavilla and Adernò (561 m.), the next town, are built on old lava plateaux of which the one of Adernò covers a considerable area. From it, the lava terrace descends at a steep angle to the Simeto, here crossed by Ponte Grande (193 m.), 370 m. below the town. Higher up the river is crossed by Ponte di Carcaci (342 m.), and still higher up it forms the fine waterfall, 15 m. in height, called Salto del Pullicino (400 m.). At all these three points, old lava flows are in evidence on both banks and in the bed of the river, which at Ponte Grande has eroded the lava to a depth of 30 m. down to the underlying sandstone, and at the other two points to a depth of 15 m., without reaching that substratum. This old, highly scoriaceous lava flow called "sciarra sterupata" still forms the river-bed for a distance of 5 km. between the points mentioned.

*Adernò-Bronté-Maletto-Randazzo, 35 km.*—From Saltodel Pullicino upwards for 15 km. the Simeto is wedged in a deep and narrow defile with precipitous sandstone cliffs on the left and steep lava terraces on the right, the two formations being thus clearly defined by the river between them. The defile, distant 2 to 4 km. from the margin of the terraces and the railway, opens out at the junction of the Simeto and the Troina, whence the former skirts the base of the Maletto sedimentary divide. It has its source in the Nebrodi range of Tertiary sandstone, north-west of Etna.

From Adernò to Bronté (793 m.), the line traverses first the lava flow of 1607 whose source was in Grotta degli Archi (2,300 m.), then the flow of Gallo Bianco of 1595 from the lateral crater of that name, and then the great scoriaceous lava tract of Passo Zingaro (700 m., 2 km. in width), one of the oldest lava fields on the west flank of Etna, with a steep cliff of 100 m. down to the Simeto. A northern branch of this old flow runs to Bronté,<sup>1</sup> which town is built on it. Between this and the Zingaro lava field the line further crosses or skirts the flow of 1843, and on the north side of Bronté that of 1832, both more or less under cultivation. Near Bronté, between it and the Simeto, rises the double-horned, prehistoric cone of Mte. La Barca (737 m.), with a tuff mud-flow on the slope below it. It is

<sup>1</sup> The town and district of Bronté, including the Maniaci (Torre Giulia) Estate below Maletto, were gifted to Nelson as Duca di Bronté by Ferdinand IV in 1799 for the admiral's assistance in quelling a rebellion in Naples.

covered with vegetation and is the most western lateral crater, 15 km. from the summit of Etna.

From Bronté to Maletto and Randazzo extends for 15 km. the Tertiary sandstone divide of the Simeto and the Alcantara, which is crossed by the railway at 974 m. altitude and culminates in Pizzo di Maletto, close to the town of that name, at 1,138 m. altitude. The sandstone divide extends on the west to the Simeto and Alcantara respectively, while its eastern slope is buried below lava fields. Of these, the principal one, between Maletto and Randazzo, is the great La Nave flow from the lateral crater of that name (1,197 m.), and nearer to Randazzo that—by repute—of 1537. Between these two, near the railway, lies the marshy lake Gurrita,<sup>1</sup> a small sheet of gaseous water in a depression of muddy clay, full only in winter and empty in summer. The fiction of its connexion with the River Amenano in Catania has already been pointed out. The extensive former oak forest on the slopes above Bronté and Randazzo, which forms part of the *regione boscosa*, has been greatly depleted, and the alpine climate and scant cultivation of this northern area contrast strikingly with the other, more especially the eastern lower slopes of the mountain. Bronté has been repeatedly ravaged, notably in 1631 and 1832, by lava flows from the lateral craters on the steep slopes above it. Randazzo (754 m.), at the base of a great lava field and several lateral craters, is built on a lava terrace 10 m. in thickness, which falls precipitously to the Alcantara, whose source is on the sedimentary divide. Bronté, Maletto, and Randazzo are all within 15 km. of the summit of Etna, the slope being at the rate of 1 in 6, steeper, more rugged, and more inhospitable than that of any of the longer approaches on the other flanks.

*Randazzo-Linguagrossa-Giarre, 39 km.*—From Randazzo the Alcantara, after flowing close below that town, takes its course along the sedimentary hills of Mojo, Castiglione (567 m.), and Francavilla (462 m.), and thence to its mouth at Calatapiano (300 m.), south of Cape Schizo.<sup>2</sup> The railway, on the other hand, skirts the margin of the lava terraces, about 5 km. from the river, to Linguagrossa, and thence to Piedimonte follows the valley of the Menessale, which is separated from that of the Alcantara by the Tertiary limestone ridge of the Castiglione hills rising to 734 m. altitude.

From Randazzo the line skirts for 8 km. the lava flows of 1624, which descended from the lateral crater of Mte. Spagnuolo (1,537 m.), and then crosses the great flow of 1879, which descended from Mte. Umberto-Margherita (2,400 m.). This flow, 10 km. in length, destroyed the road and bridge close to the present railway, and only stopped close to the Alcantara, below the village of Mojo (548 m.).

<sup>1</sup> Lake Gurrita is in Sicilian a “Gurna”, i.e. a marshy, generally muddy pool or sheet of water, of which there are several, though not gaseous, also along the coast.

<sup>2</sup> The Alcantara has now been harnessed by a hydro-electric installation of 7,000 h.p., which, jointly with that of the Cassibile, south of Syracuse, of 3,000 h.p., supplies the whole east coast of Sicily, 200 km. in length.

Above that village rises the cluster of prehistoric craters of that name at 687 m. altitude, wedged between two fiumare, which drain into the Alcantara. Of these craters, which are the extreme northern outliers of Etna, 18 km. from the summit, the largest is 200 m. in diameter. The lava flow of Mojo follows the bed of the Alcantara all the way to Castiglione and Francavilla, having eroded the lava in places to a depth of 20 m. down to the limestone. From here to Calatapiano it appears on one or both banks of the river, and at the latter place expands to at least 700 m. in width, thence continuing to the coast, where it forms the basalt cliff of Cape Schizo (23 m.), surmounted by the castle of that name. Naxos, the first Greek settlement in Sicily, founded in 735 b.c., was built on that lava cliff, which is therefore considerably older, being, moreover, overlain by ancient alluvia.

After traversing the lava flow of 1879, already mentioned, the railway skirts that of 1646, then the lateral crater of Mte. Dolce (862 m.), which lies close to the road, then the lava flow of 1809 from the Mte. Rosso crater (1,660 m.), and then, just before the town of Linguagrossa, the most recent lava flows of 1911 and 1923, which considerably damaged the railway near the station of Castiglione. On the slopes above Linguagrossa extends the still considerable forest of the same name, and higher up the lava flow of 1865. Both that town and Piedimonte (348 m.) are built on lava, the former on the pale grey variety which bears its name. From Piedimonte the line skirts the barren lava flow called *sciarra della scoreia vacca* (651 m.), then runs on alternate lava and creta terraces which overlook the extensive alluvial plain of Mascali and Calatapiano and descends to the coast at Giarre and Riposto, where it joins the main coastal railway.

*Giarre-Aci Reale-Catania, 30 km.*—Near Giarre (44 m.) the railway crosses three considerable fiumare, which descend from outside the northern slopes of Valle del Bove, but not from that valley itself. The line skirts the margin of the superposed lava terraces of Macchia, Bongiardino, and S. Tecla, above which descends the great lava flow of 1284 from Valle del Bove, which reached the upper terrace of Milo, Ballo, and Zaffarana (564 m.) ; further on the great flow of 1792, and still further, below Fleri, the flows of 1329, 1820, and 1334, the first of which reached the sea. It then runs along the terrace of Aci Reale, previously referred to, and, skirting the terraces of Trezza (overlooking the seven Cyclopean islands) and Aci Castello, reaches Catania.

The principal, historically authenticated lava flows around the peripheral base or immediately above it number more than thirty, apart from the older juxtaposed or subjacent lava- and ashfields, while more than double that number are piled up on the upper flanks in the regione boscosa and around the base of the central cone. At least equal is the number of lateral cones and craters on the lower flanks of the mountain within 5 km. from the marginal terraces.

## X. THE CENTRAL CONE AND ITS APPROACHES FROM THE SOUTH.

*The Ascent on the South Flank.*—This, the longest but the most convenient and most instructive ascent of the summit of Etna from the coast, is by the road from Catania to Nicolosi via Gravina and Mascalucia, or from Aci Reale by Trecastagni and Pedara. Both lead at first through the luxuriant *regione coltivata* and then by a steeper ascent to Nicolosi (698 m.), the well-known starting-point for the summit. The Catania road runs in part between the lava fields of 1408 and 1669, and then across the lava terraces of Le Miani, while that of Aci Reale is, near Pedara, flanked on the right by a cluster of ten lateral craters, including Mte. Peluso (933 m.) and Arso (1,033 m.). Near Mascalucia and Gravina, on the Catina road, lie the remarkable fissure, 3 km. long, of Cefalo, and the crater of Pomiciari di St. Maria (400 m.), which were the joint source of the eruption of 1381, and are the lowest points of eruption on the south flank, 22 km. from the summit.

Immediately north-west of Nicolosi, which has repeatedly shifted its site after disastrous eruptions, rises the famous double-horned ash- and scoria cone of Monte Rossi, the source of the great lava flow of 1669. Its twin craters are linked by a ridge with a midway outlet channel. The higher of the two peaks rises to 950 m. altitude, or 250 m. above Nicolosi. The cultivated cone slopes have an angle of 28 degrees, but the crater walls are much steeper. After the eruption of 1669 the area in and around Nicolosi was covered with a layer, 3 m. thick, of black sand, which only within the last century has gradually given place to cultivation. To the north-west of the village lies the cistern which was invaded by the lava flow of 1910 and caused a violent explosion.

*The Regione Boscosa.*—North of Nicolosi, at about 1,000 m. altitude, the road enters the *regione boscosa* and with it the great belt of lateral craters which flank the road in dense groups on either side. The great fissures on which these ash- and scoria cones were piled up run in the direction north to south; hence the south flank of Etna has always been the one most exposed to eruptions. The multiplicity of cones and craters, of which more than twenty are crowded together on either side of the road in a distance of only 8 km., presents a most chaotic appearance, some of the older cones being half-buried under more recent lava flows, while others have been encircled or partly demolished. The prevalent yellow colour of the ash, lapilli, and scoria cemented to tuff contrasts strikingly with the dark-grey or black lava and the green of the ferns which abound in this wooded belt of lateral craters.

*The Central Cone.*—At the upper end of the *regione boscosa* the road reaches two conspicuous lateral craters, Mte. Vettore (1,829 m.) on the left and Mte. Nero del Bosco (1,750 m.) on the right, and further on, after passing Casa Cantoniera (1,882 m.), the lower refuge of the Italian Alpine Club, it reaches another conspicuous lateral crater, Mte. Castellazzi (2,172 m.). It is at this point, i.e. at the

2,000 m. contour line, where the slope steepens, that emerges the central cone, which from here rises at about 20 degrees through the *regione deserta* to the circular plateau or old crater rim of Pian del Lago (2,942 m.). This plateau, on the margin of which stands Casa Etnea,<sup>1</sup> the new observatory and Alpine station erected in 1880, forms the upper end of the relatively easy slope of Pian del Lago proper, by repute at one time a shallow lake or snow-basin, later filled up and raised by repeated showers of ash, lapilli, and scoria. Its rise is 1 in 5, except the last, steeper part up to the plateau.

In this section of 5 km. from Mte. Castellazzi to the former Pian del Lago crater rim the road passes on the right the formidable lateral cone and crater Montagnola, 300 m. high (2,642 m.), built up of whitish yellow ash and red scoria during the great eruption of 1763. Its horseshoe crater, 150 m. in width, is open to the south, and part of the lava flow of which it was the source, is still in evidence from the outlet channel southwards. Its summit, although 700 m. lower than that of Etna, is of imposing appearance ; on its northern base it is flanked, like many of the larger lateral cones, by a satellite crater—Montagnola Piccola. The eastern base of Montagnola stands on the very edge of the great precipice of Valle del Bove, and 3 km. to the north a smaller lateral crater (2,800 m.) of 1819 occupies a similar position.

About half a km. north of Montagnola, on the Pian del Lago slope at 2,650 m. altitude, lies the great circular subsidence trough called La Cisterna, suddenly formed during the eruption of 1792 in Valle del Bove. It is 240 m. in diameter and 300 m. deep, generally filled with snow. On the plateau itself, within 500 m. from Casa Etnea, rises the ash and lapilli mound known as Torre de Filosofo (2,919 m.), by tradition the site of Empedocles' habitation<sup>2</sup> before his supposed tragic death in the summit crater. It is more probably connected with a building erected for the Emperor Hadrian's ascent of Etna, as is shown by the remains of a Roman structure, later buried under the mound by lapilli and ash showers. The Pian del Lago slope and the sheltered site of Casa Etnea have been singularly immune from lava flows in historic times, although those of 1787 on one side and of 1863 on the other closely approached the locality.

Opposite Montagnola, on the left of the road, rises the large prehistoric double-peaked lateral cone of Mte. Frumento S.<sup>3</sup> (2,843 m.), near whose western base was the source of the eruption of 1879 on the south flank of the mountain, as distinguished from the

<sup>1</sup> The present Casa Etnea has taken the place of the old Casa Inglese, erected at the instance of some British officers under the direction of Mario Gemmellaro in 1811.

<sup>2</sup> The tradition or legend is that Empedocles threw himself into the crater, leaving one of his sandals on the floor as evidence.

<sup>3</sup> Frumento S. (south flank), as distinguished from Frumento N. The names of these and other lateral craters, e.g. Arso, Pomiciaro, Nero, Rosso, Peluso, etc., as also of Grotta Palombe, are used indiscriminately all round the flanks of the Etna.

simultaneous eruption on the north flank. West of Mte. Frumento lies Mte. Pecoraro (2,214 m.), a large double-peaked crater of red scoria, the source of the lava flow of 1321. On the north flank of the mountain the highest altitude craters are Mte. Grigio, Pizzillo, Scoperto, Nero, Umberto-Margherita (1879), and Frumento N.; all between 2,000 and 2,400 m. altitude. All these constitute the highest altitude craters seated on the flanks of the central cone up to 2,800 m. or 500 m. below the summit. The lateral craters around the base of the central cone between the 1,800 and 2,000 m. contour lines number over thirty. All these cones and craters lie in a chaotic accumulation of mostly prehistoric lava- and ashfields in the regione deserta which characterizes the upper flanks of the mountain. The formidable dimensions of most of them show what must have been the magnitude of the explosive and effusive eruptions of the central crater and on the flanks of its cone during the volcano's activity in prehistoric down to early historic times.

## XI. THE CENTRAL CRATER AND ITS EVOLUTIONS.

Although no reliable records exist of the form and dimensions of the central crater before Strabo's graphic description of about 30 B.C., there is conclusive evidence around the present summit of Etna of a large elliptic crater in prehistoric times, later followed by Strabo's crater, then by Borelli's crater of 1669, and finally by the present terminal crater.

1. *The Elliptic Crater.*—The evidence of this crater consists in remains of three sectors of its periphery in the form of bosses of reddish basaltic and phonolitic lava, which are much older than the historic lavas and bear close resemblance to those of Valle del Bove. The position and the connexion between them show the crater to have had its axis in the direction of north-west and its circumference to have been 5 km., corresponding to a major and minor width of 4 km. and 3 km. respectively. Its centre lay 1 km. north-east of the present crater. Its altitude was 2,900 m., the same as that of the Pian del Lago plateau, which its southern periphery intersected near the present Casa Etnea.

In addition to the three still existing sectors of an aggregate length of one-third of the whole circumference, a large plateau (1,000 × 500 m.) on its northern periphery, also at 2,900 m. altitude, formed an integral part of it. On the east its flank overlapped the wall of Valle del Bove until it collapsed during a paroxysmal eruption and crashed into that great cirque. At the same time the eruptive axis shifted from the elliptic crater 1 km. south-west, where it formed the circular crater later described by Strabo. The cone of that crater, and with it the crater itself, were gradually raised, so that in Strabo's time it was 300 m. higher than the elliptic crater and the Pian del Lago plateau.

2. *The Pian del Lago Crater.*—Strabo's crater, 20 stades or 4 km.

in circumference, collapsed during the great eruption of 1669, when the central cone was lowered 300 m. to the level of the Pian del Lago plateau, which thus became the new central crater at 2,900 m. altitude. This crater corresponds with Borelli's account of the eruption of 1669. It was filled up and levelled with the débris of the paroxysmal collapse of Strabo's crater and the ejecta of later eruptions, and upon this platform, 2 km. in diameter, was gradually raised the present terminal cone, 40 m. higher than the cone of Strabo's time, whose stupendous collapse was thereby more than compensated.

The Terminal Cone, built up of ash, lapilli, and scoria, has, in its outward domal, gibbose form, endured substantially to the present day, although like that of Vesuvius it is always in a state of unstable equilibrium, due to its inflation with spongy and gaseous material.<sup>1</sup> Its crater, on the other hand, has undergone, and still undergoes, more or less considerable changes after every violent eruption. After earlier eruptions the crater floor often exhibited two or more openings, or bocche and small ash cones frequently fissured, half demolished, and sometimes separated by a scoria bank. After more recent eruptions it has presented more generally the form of a single steep-walled funnel. This was notably the case after the most recent explosive eruptions of 1900 and 1911, when H. S. Washington<sup>2</sup> visited it in the summer of 1914. The terminal cone was then 330 m. in height above the Pian del Lago plateau, showing a sharply pointed rim 500 m. in diameter, or 1,600 m. in circumference. The steep conical crater walls, incrustated with ring-like sublimations, ended at a depth of 450 m. in the crater floor which exhibited a small ash cone 100 m. high and several openings or bocche emitting columns of smoke and vapour. The cone-slopes as well as the Pian del Lago plateau were covered with a layer of fine grey ash 30 centimetres in thickness mixed with small stones.

Besides the main crater, an arresting feature consisted at that time in a large, very active outer bocca on the north-east flank of the cone, 80 m. below the summit. This opening, 200 m. in diameter, was enlarging its circumference and eating its way towards the main crater. The contingent effect of a merging of the two would probably be a considerable enlargement of the central crater.

The evolutions of the summit or central crater through the shifting of the eruptive axis were preceded by even more momentous phenomena in the still earlier centre of eruption in Valle del Bove, as will appear in the following section.

<sup>1</sup> While Saussure was examining the flanks of the terminal cone soon after the eruption of 1879, an accidental slip of one of his party on the ash slope caused the opening of a large pit or bocca with an explosion of mud and imprisoned steam and water several metres high. Similar explosive internal accumulations were observed at other points round the base of the cone.

<sup>2</sup> H. S. Washington and A. L. Day, "Present Condition of the Volcanoes of S. Italy": Bull. Geol. Soc. America, 1915.

## XII. VALLE DEL BOVE AS EARLY CENTRE OF ERUPTION.

*General Features.*—This stupendous, and in several respects unique rift on the east flank of Etna extends from the wall of the central cone (i.e. from a mean altitude of 2,600 m.) 8 km. down towards the coast. At its upper end it is 5 km., at its lower end, above the villages of Milo and Ballo, 3 km. in width, its depth being, down to its floor about midway, from 1,300 to 1,500 m. At its mouth at the lower end near the fiumara of Porta Calanna the altitude is 960 m., or 400 m. higher than the two villages named. It is not, as it appears to be when viewed from above, a vast subsidence basin, nor is it, as was contended at one time, a great ravine or vallone deepened and widened by fluvial erosion. Valle del Bove is, in its upper part, a great cirque, and in its lower part lengthens, narrows, and curves inwards to a horseshoe. It is, in fact, a huge crater breached on the east, towards the sea, the former seat of a great centre of eruption convulsed by paroxysmal explosions and demolitions on an enormous scale. Its area of 32 sq. km. (13 sq. miles) is an all but waterless waste of chaotically piled up lava and tuff banks in which scattered herbs, genista, and stunted trees represent even now the only forms of scanty vegetation. It is in the truest sense a *regione deserta*. Except the fiumara of Porta Calanna, which furrows the lava banks of that name at the lower end, no streams rise within the boundaries of the horseshoe, and the surface-water of heavy rains, as far as it is not absorbed by the volcanic soil, is the only agency of occasionally transporting material by mud-flows. On the other hand, countless fiumara cracks furrow the precipitous slopes outside the rugged, roughly parallel ridges of Serra del Solfizio and Serra delle Concazze which bound Valle del Bove on the south and north respectively.

The highest points of those two ridges at their upper extremities in contact with the central cone are respectively 2,374 m. and 2,824 m. Thence the altitudes gradually decrease downwards, the lowest points being 960 m. at Porta Calanna on the right, and 926 m. at Mte. Scorsone on the left. The upper connecting ridge from Serra del Solfizio to Serra delle Concazze, 5 km. in length, abuts against the flank of the central cone, but has a gap of 2 km. near its northern end, through which broke the lava flows of 1842 from the summit crater and of 1869 from a bocca on the east flank 600 m. below the summit. Both these flows plunged down the precipice into Valle del Bove. Close beyond the highest point of Serra del Solfizio, also called *Schiena dell' Asino*, rises the great Montagnola cone formed in 1763, while contiguous to the highest point of Serra delle Concazze lies the plateau of the old elliptic crater previously described. From that northern extremity of the ridge descends into Valle del Bove the ravine called Valle del Leone, formed during the collapse of the flank of the old elliptic crater which overlapped the Valle del Bove wall like a bastion in a width of about 2 km.

*The Cirque Crater.*—It is within the great cirque that took place the earlier paroxysmal eruptions before the eruptive axis was shifted to the present summit, although even then the volcano had already been piled up to a height of over 2,500 m. A parallel case of the Valle del Bove cirque and its main crater is afforded by Somma-Vesuvius, where on the great crater, 4 km. in diameter, was eccentrically superposed the terminal cone of Vesuvius, leaving the corridor of Atrio del Cavallo and Valle dell' Inferno as an outlet. Like the crater of Mte. Somma, that of Valle del Bove is circumscribed by high, precipitous walls. The roughly elliptic outline of the rim is clearly marked by the southern sector, i.e. the curved ridge of the upper Serra del Solfizio or Schiena dell' Asino, while the eastern sector across the floor of the cirque is evidenced by a great bar or terrace—the base of the crater wall—on which are superposed, encircled by later lava flows, the bosses and projecting spurs of Mte. Zoccolaro, Mte. Finocchio, Rocca Musarra, Palombe, and Naso Giallo, at altitudes from 2,000 to 1,800 m. From the last-named point the rim of the northern and western sectors skirted the flanks of the ridge connecting Serra delle Concasse and Serra del Solfizio. The major axis of the crater floor was 5 km., the minor 3 km., at about 1,500 m. altitude, the rim varying in altitude from 1,700 to 2,000 m., as already mentioned.

*The Eccentric Trifoglietto Cone.*—Within the southern sector of the cirque crater was built up, by the shifting of the eruptive axis 2 km. to the west during a paroxysmal explosion, the eccentric cone of Trifoglietto. From its circular base at 1,500 m. altitude and 2 km. in diameter it rose to about 2,400 m., thus reaching the level of Serra del Solfizio. The reconstruction of this cone rests upon the conclusive evidence of the converging walls, banks, dykes, and veins all round its flanks and circumference. The veins up to 20 and even 50 m. in thickness are, in fact, fissures, later filled up, which converge towards the summit of the cone, just as those on the flanks of Etna converge, on a much larger scale, towards the central summit crater.

The andesitic and phonolitic lavas and tuffs of Valle del Bove, including those of the two craters, are all much older and more acid than the historic eruptive products of Etna, and exhibit close analogy to the basaltic remnants of the old elliptic summit crater, as also to the pre-Etnean basalt fringe along the coast. There is some evidence of other centres of eruption having existed in Valle del Bove besides those referred to; but the evidence, consisting in isolated veins, i.e. old fissures in the eastern lava banks, does not admit of reliable reconstruction. The petrographic characteristics of the Valle del Bove lavas will be referred to in the sequel.

*Evolutions of the Eruptive Axis.*—The Trifoglietto cone, by explosion and demolition, shared the fate of its parent crater, the eruptive axis shifted from Valle del Bove 4 km. north-west to the elliptic crater formed in the region of the present summit at an altitude of 2,900 m., or 400 m. higher than the Trifoglietto cone.

Upon the later collapse of the east flank of the elliptic crater, an enormous mass of material was precipitated into the cirque of Valle del Bove, while the eruptive axis shifted from the elliptic centre 1 km. south-west to the new centre of Strabo's, Borelli's, and the present summit crater. Thus the evolutions of the eruptive axis of Etna comprise three shifting phases: in Valle del Bove from the cirque crater to Trifoglietto, thence to the elliptic, and from the latter to the present main centre of eruption.

*Structure and Origin of Valle del Bove.*—The unique feature of the great cirque and horseshoe of Valle del Bove consists in the bowels of the mountain being laid open, like a vast quarry, to the enormous depth of 2,000 m. from the summit to the floor, the huge triangular mass blown out of the mountain side representing a volume of 32,000 million cubic metres of material. The floor of the cirque is now to a large extent covered by the enormous lava flow of 1852, whose source was in the twin craters of Centenari, which coincide with the centre of the old cirque crater and the direction of the main fissure. These phenomena, together with the stupendous lava and tuff banks of the two great parallel ridges, present a vivid picture of how the interior of the mountain was built up. Below the floor of Valle del Bove the eruptive products must attain a further depth of at least 1,000 m. to reach the creta platform at 200 m. above sea-level.

As regards the origin, formation, and present condition of Valle del Bove, and apart from the long exploded theory of upheaval and subsidence, the later hypothesis of fluviaatile erosion must be discarded as futile, because devoid of foundation and not consistent with actual phenomena.<sup>1</sup> The erosion of a drainage area of 32 sq. km. would entail the existence of a great outlet ravine or vallone from the mouth of the horseshoe down to the sea, 10 km. distant; of such an exit channel there is no trace. The steep slopes between those two points exhibit a series of four parallel vine-clad terraces composed of successively piled up old lava flows resting, at the lower levels, on creta and gravel conglomerate. In addition to these, torrential mud-flows and detritus from Valle del Bove have expanded towards the shore forming the fan-like plain of Torre Archirafi, later covered

<sup>1</sup> Lyell ("Remarks on the Origin of Mt. Etna": Phil. Trans. R. Soc. London, 1858), in combating v. Buch's and de Beaumont's theory (then in vogue) of "upheaved" volcanoes, regarded Valle del Bove as a valley mainly eroded by the River Amenano of Catania, which, according to an unreliable tradition, suddenly stopped its flow in that city during the eruption of 1669. Later, he adopted Mario Gemmellaro's, Sartorius', and Stoppani's view of Valle del Bove being an old crater cirque. Another theory he advanced was that Etna's central cone and mantle are of relatively inconsiderable height above the sedimentary platform. These hypotheses, as also the one concerning the terrace of Aci Reale, have long since been discarded as erroneous, founded as they were on insufficient examination *in situ*. The hypothesis of the thinness of the eruptive products is disproved by the depth of 2,000 m., to which these products are laid open in Valle del Bove without a trace of the sedimentary substratum.

by alluvial deposits. Perhaps the most convincing view of the contours and form of the great horseshoe is the one from that point.

The origin of Valle del Bove must be sought in a great initial rift, east to west, 8 km. in length, on which was formed the cirque crater, followed by the eccentric cone of Trifoglietto. They have their precise parallel in the later elliptic and eccentric circular craters of the present summit of Etna, and even more remarkably, as previously stated, in Somma-Vesuvius. Since the shifting of the eruptive axis to the present summit of Etna, Valle del Bove has been subjected to active atmospheric denudation and disintegration of the old lava and tuff banks, while the floor has been considerably raised not only by the accumulation of detritus, but by successive later lava flows, of which at least twelve are historically authenticated. The denudation and the accumulation of detritus will steadily continue; the further raising of the floor by new lava flows depends on the future eruptive activity of the great mountain.

### XIII. THE ERUPTIONS.

The total number of the historically authenticated principal eruptions of Etna down to the present day is over 100, of which a list is appended to this paragraph. Suffice it to briefly note here only the most outstanding of those eruptions, which in the list are marked with an asterisk.

700 B.C. to A.D.—Among the twelve eruptions recorded by the ancient Greek writers before the advent of the Christian era the earliest was in 693 B.C., and is concordantly mentioned by Thucydides and others, and later also by Lykurgus and Strabo. The lava flow on the south flank was disastrous to Catania (founded in 729 B.C.), and with it is associated the tradition of the Fratelli Pii (the pious brothers), who rescued their parents from the advancing lava by carrying them on their backs, an incident commemorated on numerous ancient Greek bronze coins. The other notable eruption was the one of 394 B.C., when the army of the invading Carthaginians was stopped on its march along the east coast by a lava flow in its advance to the sea. This lava flow cannot be, as has been assumed, the one from Mojo along the River Alcantara to Cape Schizo, the site of the ancient city of Naxos built in 735 B.C. on that lava, but must refer to one of the more southward flows. The third eruption of 122 B.C. was again on the south flank, and disastrous to Catania, invaded by the “Carvana” flow in the northern area of the city. The later eruptions of 49, 44, and 36 B.C. are by tradition associated with sinister political events, e.g. Caesar’s death, Roman civil wars, etc.

A.D. to Sixth Century.—During the first five centuries A.D. only five eruptions are recorded, of which the most disastrous one of 252 was again on the south flank, Catania being, according to the previously mentioned tradition, saved from destruction by the display of St. Agatha’s, the martyr-saint’s, veil, which relic claims

to have miraculously stopped or deflected advancing lava flows in the whole region of Catania and Nicolosi ever since. Every recorded occasion of its display down to the present day is, at any rate, proof of a violent eruption having taken place.

*Fifth to Eleventh Century.*—After the great gap of records during the dark ages following on the fall of Rome, the first authentic eruption was that of 1064, by tradition associated with Roger I's invasion and the consequent Norman occupation of Sicily.

*Eleventh to Twelfth Century.*—In the twelfth century the most violent eruption out of eight recorded took place in 1169, when a lava flow down the south flank, and a still more terrible earthquake once more destroyed Catania and devastated the surrounding area.

*The Thirteenth Century* was marked by only three recorded eruptions, of which the one of 1284, coinciding with the death of Charles of Anjou, took place in the lower part of Valle del Bove, a great scoriaeous lava flow called "Femina morta" expanding below on the slopes of Milo, Ballo, and Zaffarana.

*The Fourteenth Century*, among six recorded eruptions, includes the violent one of 1329 simultaneously on the east and south flanks, on the former from Rocca Musarra in Valle del Bove, on the latter from Mte. Rosso di Fleri, 6 km. from the coast, north-west above Aci Reale. The lava flow from the latter source reached the sea at St. Tecla, 5 km. north of Aci. A southern branch of this flow threatened Catania, when St. Agatha's veil again came into play. Another notable eruption was that of 1381, which devastated the slopes north of Catania.

*The Fifteenth Century* witnessed six eruptions, among them the violently explosive and effusive one of 1408, when the pine-cloud of the summit crater projected ash, mixed with snow torn from the rim, as far as Messina, while a great lava flow from Mte. Nero del Bosco above Nicolosi devastated those eastern slopes, St. Agatha's veil coming again into requisition, as it did also in the eruption of 1444 from Mte. Arso on the south flank, 4 km. north of Nicolosi, the lava flow descending towards Catania.

*The Sixteenth Century*, in which eleven eruptions are recorded, was chiefly remarkable for the great outbreaks of 1536 and 1537, when the Emperor Charles V was in Sicily. These two eruptions, in March and May respectively, were characterized not only by considerable lava flows, but even more by violent and protracted earth-shocks and explosive phenomena, the ash clouds of the summit crater spreading all over Sicily and part of Calabria. The source of the 1536 lava flows was between Mte. Castelazzi and Serra del Solfizio, at 2,000 m. altitude, the lava flowing in three streams, one south-east towards Catania, a second one south towards Nicolosi, and a third south-west to Adernò, circumventing the lateral crater of Mte. Minardo above that town. The melting snow of the central cone caused serious torrential floods, which mingled with the lava and gave rise to the erroneous report that Etna had vomited volumes

of water like the Icelandic volcanoes. The eruption of 1537, on the same fissure, proceeded from Mte. Nero del Bosco (1778 m.), its lava flow extending 10 km. south to Nicolosi and Monpilieri. During the simultaneous explosions on the summit crater, part of the wall of the latter collapsed, as had already been the case during the eruption of 1444.

*Seventeenth Century.*—The activity of Etna increased considerably in this century, when no less than sixteen more or less violent eruptions were registered. Notable among these outbreaks were the continuous eruptions from 1634 to 1638, when lava flows from the base of the central cone (2,000 m.) on the south flank descended 10 km. to the eastern slopes of Fleri and Zaffarana. Again, in 1651, a lava flow on the west flank descended to Bronté, and another on the east flank from Mte. Arsi to Mascali and the sea, this highly scoriaceous flow being named “sciara della scoria vacca”, the scorched cow. On the north flank two great eruptions took place in 1610 and 1646, the lava flows descending from Mte. Nero (2,079 m.) 10 km. down to the plain of the Alcantara.

Upon these outbreaks followed the eruption of 1669, which constitutes a landmark in the history of the volcano, and initiated a phase of eruptive activity which has lasted down to the present century. The formation of the double lateral cone of Mte. Rossi (948 m.) near Nicolosi, and the enormous lava flow 16 km. in length from its twin craters, devastating the whole mountain-side down to Catania, Misterbianco, and Belpasso, were accompanied by a succession of gigantic ash clouds and explosions from the summit crater. The latter was blown up and the cone was lowered 300 m. to the present Pian del Lago plateau, as previously described. The lava flow covered an area of 128 sq. km. (50 sq. miles) at an average depth of 8 m., equal to a volume of 1,000 million cubic m. This monumental eruption, the largest on record in historic times, was followed by a quiescence of thirteen years.

*The Eighteenth Century* was marked by no less than eighteen eruptions, more especially those of 1755, with an overflow of lava from the summit in three directions, i.e. to Masiali (south-east), Linguagrossa (north), and Bronté (west); and of 1763, when the great Montagnola cone (2,644 m.) was piled up, from whose crater a lava flow descended 12 km. to Nicolosi. In the same year a lava flow descended from Mte. Nuovo on the west flank to Bronté, which had already been visited by a similar flow in 1723. The last great outbreak of that century was that of 1792, with lava flows from three points; one, from the west base of the terminal crater (2,300 m.) towards Adernò; another, on the east, from Serra del Solfizio (2,300 m.) down into Valle del Bove; and a third, also on the east, from Pian del Lago (2,500 m.) down the steep slopes towards Zaffarana. The same eruption caused the great subsidence trough of the Cisterna (2,600 m.), Pian del Lago. The eruption of 1792 was followed by a repose of eight years.

*The Nineteenth Century* witnessed still greater activity, i.e. a series of twenty-one eruptions with quiescent intervals of seven, twelve, and ten years. In 1808 the terminal crater had a circumference of 1,200 m. (400 m. in diameter), was 300 m. deep, and exhibited on its floor two vents, 60 m. from each other. Among the great eruptions of that century are prominent those of 1843, with a great lava flow from the west base (2,000 m.) of the central crater to Bronté, Adernò, and the old Zingaro lava field; of 1852 from the Centenari twin-craters in the centre of the Valle del Bove cirque (1,500 m.), with the largest lava flow of that region, covering the whole floor and extending to the villages of Ballo and Zaffarana on the terrace below; and of the great lava flow of 1865 from Mte. Frumento, north-east (2,200 m.) in two streams east and north-east, towards Mascali and Linguagrossa, the largest flow on that flank of Etna, computed at 70 million cubic metres.

The last great eruption of the nineteenth century was that of 1879, lasting all November and December. During this outbreak the whole south and north flanks of the central and terminal cones, including the summit, were rent in twain, the continuous fissure of up to 2 m. in width and the chain of fumaroles on it being over 13 km. in length. On the south flank, the lava flow stopped at 2,000 m. altitude; but on the north flank extended a lava flow from the newly formed cone and crater Mte. Umberto-Margherita (2,400 m.), 10 km. down to the Alcantara, not far from Mojo. Except the fissure across the terminal cone, the form of the central crater was not affected by this great eruption. The further eruptions of 1883, 1886, and 1892 on the south flank all followed the fissure of 1879, the lava flows having their sources at rising altitudes of 1,000, 1,540, and 1,800 m. altitude. In the central crater, explosive strombolian activity continued intermittently from 1893 to 1899 and 1906.

*The present century*, which has already a record of three eruptions, witnessed in 1908 an enormous explosion and ash cloud from the summit crater, and the simultaneous opening of a fissure on the crest of the ridge connecting Serra del Solfizio and Serra delle Concazze in Valle del Bove at 2,500 m. altitude. This fissure descended to Trifoglietto (2,000 m.), and on it formed a chain of explosive craters and effusive bocche, from which latter a lava flow ran east to a distance of about 2 km. In 1910 a fissure opened on the south flank near Mte. Castellazzi (2,170 m.). The lava broke out at 2,300 m. altitude and descended the south flank along the fissure of 1879 to a point 1,970 m. altitude, 1 km. below Mte. Castellazzi, where, finding that fissure plugged, it exploded and the pulverized material formed a large horseshoe crater which was named Mte. Recupero by some and Mte. Riccò by others. From this new crater the main flow of lava continued through the *regione boscosa* and entered the *regione coltivata* in two streams, one stopping short of Borello-

Belpasso, the other of Nicolosi.<sup>1</sup> The length of this lava flow is 9 km. Another violent eruption occurred in 1911 on the north-east flank at the base of the central cone at 2,000 m. altitude, and later in a crater lower down, whence a large lava flow 150 m. broad descended the mountain side to a distance of 8 km., where it wrought great havoc and destroyed over 1 km. of the circum-Etnean railway west of Castiglione station. A third, large, actively explosive vent or bocca was also formed on the north-east slope of the central cone, 80 m. below the summit rim.

Since 1911 Etna has been in a state of intermittent quiescence. During this time the phenomena of periodical, more or less explosive dense smoke and vapour columns from both the central and the now adjoining new lateral crater with ejections of stones, etc., were essentially strombolian in character. The new crater, which Washington found active in the summer of 1914, was again very active both in March, April, and September, 1922, while the great central crater was in repose.

The same lateral crater continued intermittently active down to 1923, when, on 3rd April, after a premonitory explosive vapour and scoria cloud, it vomited a sluggish lava stream which, 6 m. broad, flowed slowly east towards the Valle del Bove, but stopped on the brink of that chasm. Its length was 3 km. On this occasion, too, the central crater remained inactive, which points to its orifice being temporarily plugged, so that the explosive and effusive material in the chimney had to find its outlet through the lateral crater.

This eruption was followed only three months later by a more violent one on 16th June, when, after a severe earth-shock, the central crater suddenly reopened and threw up a great ash cloud, while on the north flank, near Mte. Pizzillo (2,300 m.), a violent explosion opened a large fissure from which a lava stream flowed due north in the same direction as the one of 1879. It dispersed after a flow of a few kilometres. At the same time another, larger lava stream flowed from several new vents near Mte. Nero at 2,000 m., not far from Mte. Pizzillo. This followed the same north-east direction as the streams of 1900 and 1911, and after overwhelming the Etnean railway at Castiglione station, deviated towards the town of Linguagrossa, where it stopped after a flow of 8 km., having expanded to a width of 1 km. A marked feature of this, the most recent, eruption, of four days' duration, were the large subsidences which formed both in the central and the lateral crater, and opened an underground passage for the lava emerging near Mte. Pizzillo, 1,000 m. below the summit. Near Mte. Nero the exploded pulverized

<sup>1</sup> A noteworthy feature of the 1910 flow, which at one point expanded to over 1 km. in width, was its agitated, rapid movement over broken ground, with parallel rows of constantly changing lava seracs floating in the turbulent current. The late V. Sabatini who observed this phenomenon (*op. cit.*) called these seracs—up to 100 m. in length and 10 m. in height—“*creste in deriva*”, i.e. of secondary formation, like icebergs detached from a glacier.

material quickly formed, as usual, a new cone and crater on the fissure connected with the summit crater.

*Summary.*—The foregoing record shows that from the sixteenth century down to the present day the number of eruptions has steadily increased from eleven to twenty-one per century, equal to an average of seventeen per century or one eruption every six years. Curiously enough a similar average (seven years to one eruption) works out in the case of Vesuvius since the seventeenth century.<sup>1</sup> It does not, of course, include the purely explosive eruptions from the central crater, which, if unaccompanied by lava flows, are locally called abortive eruptions.

Of the thirty-five historic lava flows around the peripheral base, twelve are in evidence on the south flank, nine on the north, eight on the west, and six on the east flank. The largest number corresponds therefore with the direction of the fissure most frequently in operation, i.e. south to north across the central and terminal cone. This is further confirmed by the computed volumes of the following largest historic lava flows on record :—

1669, 16 km. in length,	on south flank,	1,000 million cubic metres.
1763, 12	" " on south and west flanks,	45 "
1852, 7	" " in Valle del Bove,	400 "
1865, 11	" " on north flank,	70 "
1879, 12	" " on south and north flanks,	50 "
1886, 9	" " on south flank,	30 "
1892, 7	" " on south flank,	50 "
1910, 10	" " on south flank,	20 "
1911, 8	" " on north flank,	10 "

Some of the largest prehistoric lava flows, e.g. the Zingaro field on the west, the Mojo-Alcantara flow on the north, and the old Catania flows on the south flank, may be computed as fully equal to the great flow of 1669, i.e. 1,000 million cubic m. It is a noteworthy feature that the largest lava flows have decreased in magnitude of volume, while, as previously shown, the aggregate number of eruptions per century has increased.

Apart from the lava flows, an instance of the enormous scale on which Etna works is the volume of the summit cone and crater of 1669, whose collapse and lowering by 300 m. represents a computed volume of 1,000 million cubic m. of material, equal to the volume of the largest lava flow of the volcano. Another instance is the formation, in the space of a few days, of the comparatively recent lateral cones and craters of Mte. Umberto-Margherita (1879), Montagnola (1763), and Mte. Rossi near Nicolosi (1669), of which

<sup>1</sup> Equally noteworthy is the fact that both Vesuvius and Etna ushered in their new period of activity at about the same time, i.e. by their great eruptions of 1631 and 1669 respectively. That coincidence points, however, not to a magmatic correlation, but to meteorological or physical causes, such as high atmospheric pressure or electric phenomena reacting on the rock strata down to the seats of the magma.

The largest historic lava flow of Vesuvius was 27 million c.m. (1794), of the Lazio (Rome) 45 million c.m. (prehistoric).

the first represents a volume of 25 million cubic m., and the two others, the largest lateral craters of Etna, represent 42 million and 50 million cubic m. respectively, thus exceeding that of Mte. Nuovo in the Phlegræan Fields (39 million cubic m.). They show that the volume of ash, lapilli, and scoria piled up in a lateral cone may equal or exceed that of a great lava flow, irrespective of the enormous ash showers ejected by the summit crater. The 200 lateral craters on the flanks of Etna, at an average volume of 40 million cubic m. each, thus represent a total of 8,000 million cubic m., apart from the ash fields and tuff banks which alternate with the lava flows. The 200 lateral craters must represent at least as many eruptions and corresponding lava flows, of which half belong to the historic, and the others to the later prehistoric period, apart from those of the earlier prehistoric period, buried and reaching down to the sedimentary platform.

#### XIV. LIST OF RECORDED ERUPTIONS.

N.B.—The greatest paroxysmal eruptions are marked \*.

	Century.	Eruptions.	
I Period.	To 700 B.C.	Prehistoric	In middle, later, and post-Quaternary times down to 700 B.C.
II Period.	700 B.C.-A.D. 1	12	693*, 475, 425, 394, 350, 141, 135, 126, 122*, 49, 44, 36.
	1st-6th A.D.	5	38, 40, 72, 252*, 550.
	7th-10th	—	No reliable records.
	11th-12th	8	1064, 1157, 1160, 1164, 1169, 1175, 1194, 1197.
	13th	3	1222, 1250, 1285*.
	14th	6	1321, 1328, 1329*, 1333, 1350, 1381*.
	15th	6	1408*, 1444*, 1446, 1447, 1470, 1494.
III Period.	16th	11	1533, 1535, 1536*, 1537*, 1540, 1541, 1554, 1566, 1578, 1579, 1580.
	17th	25	1603, 1607, 1610*, 1614, 1619-24, 1634-8*, 1643, 1646*, 1651, 1654, 1669*, 1682, 1688, 1689, 1693, 1694.
	18th	19	1702, 1723*, 1724, 1732, 1735, 1736, 1744, 1747, 1751, 1752, 1755, 1759, 1763*, 1764, 1766, 1780, 1781, 1787, 1792*.
	19th	21	1802, 1809, 1811, 1812, 1819, 1832, 1838, 1842, 1843*, 1852*, 1863, 1864, 1865*, 1869, 1874, 1876, 1879*, 1883*, 1886*, 1892, 1899.
	20th	4	1908*, 1910*, 1911*, 1923.
		120	

## XV. CONCLUSION.

1. Etna, bounded on the east by the Ionian sea, and inland by a semicircular belt of Tertiary sandstone, is built up subaerially to a height of 3,300 m. on a platform of Pliocene creta (marl and clay), which forms the greater part of the substratum up to 200 m. above sea-level. The north-west sector of the mountain abuts against the slope of a sandstone spur whose highest elevation is 1,100 m. above sea-level.

2. The subaerial activity of Etna, extending from middle and later Quaternary times down to the present day, comprises three periods :

- (1) The prehistoric, down to 700 B.C.
- (2) The early historic, from 700 B.C. to the sixteenth century A.D. ; and
- (3) The recent historic, from the sixteenth century to the present day.

During the third period an eruption has, on an average, taken place every six years. The eruptions of that period show a gradual decrease in the volume of the largest lava flows, but an increase in the number of less violent outbreaks.

3. To the prehistoric period belong the pre-Etnean basalts of the coastal cliffs, the oldest, lowest andesitic and phonolitic lavas of Valle del Bove, and the similar ones of the old elliptic crater of the summit region. The lavas of the two historic periods are uniformly basaltic of low basicity without any material mineral or chemical change during the eruptions of 2,000 years. The prehistoric (andesitic and phonolitic lavas) owe their higher silica percentage to their alteration from basalts by pressure under high temperature. Etna thus affords a conclusive example of the never-ceasing process of rock metamorphism. None of the Etnean lavas are leucitic.<sup>1</sup>

4. The 200 lateral cones and craters are formed on fissures converging towards, or radiating from the central or summit crater. Many of these lateral cones have twin craters, as similarly the central crater often exhibits on its floor twin vents in the form of small juxtaposed cones, and satellite cones are formed outside, i.e. on the slopes or at the base of the terminal cone.

Apart from the effusive material of lava flows, the aggregate explosive material (ash, lapilli, and scoria) of an eruption is made up (a) of the volume of the piled-up lateral cone—or cones ; (b) of

<sup>1</sup> Some crystalline, thickly incrustated rock fragments among the enormous number of ejecta of the Montagnola eruption of 1763 were erroneously regarded as granite from a source more deep seated than the sandstone. They contained, however, no quartz, and were simply pieces of very old lava, altered like that of the lowest banks of Valle del Bove, which probably extend into and form the bulk of the lower parts of the mountain as the products of its earliest eruptions.

the additional ejecta of the crater within its radius of explosion ; and (c) of the enormous volume of the material simultaneously ejected by the pine-clouds and showers of the summit crater, this material being, owing to the high altitude of 3,300 m., dispersed over a radius far beyond the area of the mountain. The ratio of lava to ejecta during a paroxysmal eruption may be estimated as varying from 1 : 100 to 1 : 200. Exceptions are the disproportionately huge lava flows of 1669 and 1852.

5. A phenomenon characteristic of Etna is that, with rare exceptions, the eruptions take place during autumn, winter, or early spring, i.e. in the season of heavy rains, snow fall, or melting snow respectively. Even the rare eruptions in summer are but the climax of the premonitory, preparatory activity by earth-shocks or strombolian explosions in winter or spring.

The snow-cap of Etna from 3,300 m. down to the 2,000 m. contour line, i.e. in a radius of 1,000 m., covers an area of 80 sq. km. which, at a mean depth of 2·5 m., represents 20,000 million cubic m. Allowing half of this volume for surface drainage and evaporation, 10,000 million cubic m., or tons, are annually absorbed by the mountain, which thus acts as a gigantic filter, or in the words of Pindar as "a mighty sucker of snow".

It is therefore not improbable that the enormous underground accumulations of snow and rainwater percolating to the seats of the molten magma, are, like infiltrations from the sea, contributory factors of internal explosions, which in periods of latent activity find their outlet in columns of smoke and vapour, and in periods of acute activity in violently explosive eruptions.

6. In area, height, volume, and in the magnitude of its eruptions, lateral craters, and other volcanic phenomena, Etna far surpasses all other volcanoes of Continental Europe. Among the most prominent Italian volcanoes, the Lazio (Albano) group near Rome is only one-third in area and height, Somma-Vesuvius only one-sixth in area and little more than one-third in height, while in computed volume it is only one-fifteenth of Etna.<sup>1</sup> In eruptive potentiality proportionate to their respective size, Etna and Vesuvius are, to judge from their activity in the present century, on a par, though in the magnitude of its lava flows the Sicilian giant will always be *facile princeps*. Both are still vigorous, though neither is likely further to increase in height. With the gradual decline of their activity, denudation will become a dominant factor, and with increasing vegetation they will eventually assume the peaceful garb of the other, now extinct, silent, and wood-clad volcanoes of Central and Southern Italy.

7. Etna affords no direct evidence of the depth of its magmatic

<sup>1</sup> Considering the two volcanoes roughly as pyramids, the computation of their approximate volume works out as follows : —

Somma-Vesuvius, area 200 sq. km.  $\times$  0·4 km. ( $\frac{1}{3}$  the height) = 80 cubic km.  
Etna, area 1,200 sq. km.  $\times$  1·0 km. ( $\frac{1}{3}$  the height) = 1,200 cubic km.

reservoir below the surface, but that depth may be computed by the formula already applied to Mte. Nuovo and Vesuvius, pp. 79 and 104. Considering a lava flow of 125 million cubic m. (the mean of the five largest flows of the nineteenth century) as a cylindrical solid in the central chimney 200 m. in diameter, the height of the chimney would be about 4,000 m., of which 3,000 m. above and 1,000 m. below sea-level. The latter figure thus represents the probable thickness of the sedimentary platform of the volcano, the former the height of the volcano itself.

The enormous explosive force required to lift a column of lava from the reservoir to the summit accounts for the multiplicity of secondary craters at lower levels as ramifications of the trunk chimney. The upper part of the latter is thus being more and more relieved of lava flows and acts now mainly as the principal explosive vent of ash clouds and ejected pulverized material.

8. With the depth of the magmatic reservoir below the surface is closely allied the problem of the connexion of the reservoir with the interior of the earth below the latter's crust of an estimated thickness of 40 km. or 25 miles.<sup>1</sup> According to three conflicting theories the nucleus of the earth is gaseous, fluid, or solid. The process of solidification of the interior (roughly 6,400 km. or 4,000 miles to the centre) must therefore be either downwards towards the centre, or from the centre upwards. Hence the earth's crust ( $\frac{1}{150}$ th of the total thickness) must be in contact with an interior either solidified or totally fluid, or with an intermediate fluid zone or belt which constitutes a continuous magmatic reservoir and by great faults and cracks in the crust communicates with the volcanic centres. In the case of Etna, this theory involves a prodigious explosive force to lift a column of lava to the summit, i.e. to a height of 43 km.

It is therefore more probable that volcanoes are directly fed, not from a deep-seated, continuous, fluid zone, but from independent reservoirs which lie in great cavities of the earth's crust at moderate depths below the surface. If the interior below the earth's crust is fluid, either wholly or only within a narrow zone, those reservoirs may communicate with the same; but they may also be self-acting, viz. by superincumbent pressure, circulating hot springs, and consequent molecular change, the rock material may reach the critical temperature and be kept in a state of fusion and fluidity at a depth far less than 25 miles. Curiously enough this probable solution of the problem was, in a crude form, adumbrated by Strabo's conception of the existence of great subterranean caves and cauldrons of "fire" along the Neapolitan coast and the east coast of Sicily.

<sup>1</sup> This estimate of thickness rests on the empirically established normal increase below the surface of 30 deg. C. per km., the critical temperature of rock fusion being 1,000-1,500 deg.; mean 1,200 deg. at 40 km., or 25 miles.

TABLE.—AREA AND ALTITUDES OF THE PRINCIPAL VOLCANOES OF CENTRAL AND SOUTHERN ITALY.

		Area. sq. km.	Altitude. m. above sea-level.
Etna	.	1,200	3,300
Somma-Vesuvius	.	200	1,250
Vulture	.	100	1,330
Roccamonfina	.	200	1,005
Phlegræan Fields	.	100	458
Epomeo (Ischia)	.	50	792
Lazio (Albano)	.	400	956
S. Etruria (Bolsena, Viterbo, Bracciano)	.	3,600	1,053
Amiata (Tuscany)	.	200	1,734

### XVI. PETROGRAPHIC NOTE.

I. *Pre-Etnean Basalts*.—These comprise the coastal fringe of submarine formation from Motta St. Anastasia, west of Catania, to Aci Reale, north of that city. The basalt of the Motta and Paternò cliffs is of grey to brownish black colour, slightly doleritic in texture, and porphyritic in structure; its matrix, partly with vitreous base, is composed of predominant basic plagioclase and less augite, much altered olivine, magnetite, and accessory apatite, chlorite, and calcite.  $\text{SiO}_2$  47 to 49 per cent.

The basalt of the cliffs north of Catania, notably of the Cyclopean islands, is very similar to the above but more doleritic and vesicular, with cavities filled with calcite. The partly vitreous, brown base is more decomposed, phenos of augite are more numerous, and olivine appears only in small grains. With this basalt corresponds that of the lower, submarine banks of the Aci Reale terrace.  $\text{SiO}_2$  48 per cent.

II. *The Oldest Lava of Valle del Bove*.—These lavas are essentially augite-andesites, rough to the touch, dull pale grey to reddish in colour, and porphyritic. In the plagioclastic, porous matrix are disseminated predominant lamellar, often vitreous phenos of labradorite and anorthite, of brown to yellow augite, and apatite; both olivine and mica are absent.  $\text{SiO}_2$  57 per cent.

The phonolitic variety, in tabular layers, is more fine-grained in the matrix of micro-plagioclase and augite; these appear also as small phenos, with some olivine, mica, and magnetite; no apatite.  $\text{SiO}_2$  55 per cent.

The augite-andesite of the great veins up to 20 and 50 m. in thickness is conspicuous by its green to grey-green colour. The matrix is a chaotic aggregate of basic plagioclase largely vitreous (anorthite), very poor in augite, rich in magnetite, some hornblende, little olivine.  $\text{SiO}_2$  58 per cent.

To the first of these three varieties belongs also the lava of Mte. Calvario near Biancavilla.

III. *The Old Terrace Lavas*.—These comprise notably the terraces and banks of the Simeto on the west flank of Etna. Grey in colour, their groundmass is an aggregate of basic plagioclase and augite,

the former generally predominant with vitreous base between the two minerals. Phenos of the same appear with abundant magnetite, some olivine, and apatite. These terrace lavas, as also the upper banks of the Aci Reale terrace and the upper lava banks of Valle del Bove, are much more plagioclastic and less augitic than the oldest, lowest Etnan lavas. They are essentially porphyritic basalts.  $\text{SiO}_2$  40 per cent.

IV. *The More Recent Lavas.*—These dark-greyish to black porphyritic lavas are conspicuously doleritic in texture and constitute the bulk of all the historic and more recent eruptions in the following varieties.

1. *Predominantly Plagioclastic.*—These are fine-grained and porphyritic, the matrix being an aggregate of basic plagioclase with abundantly disseminated magnetite and little augite; with the phenos of the same are associated some olivine and apatite. These basalts occur typically near Casa Etnea and in the uppermost more recent banks of Valle del Bove (1792 and 1819 lava), as well as in the great Femina morta lava field below the latter (1284 lava). A variety of this lava, of pale grey colour, whose matrix is predominantly plagioclastic with subordinate augite and magnetite and only plagioclase phenos, occurs notably in the Carvana and other lava fields of Catania (122 B.C., 1381, and 1643), also near Randazzo (1537), near Bronté (1832 and 1843), and at Linguagrossa.  $\text{SiO}_2$  49 per cent.

2. *Plagioclase and Augite in equal proportions.*—Of this dark-grey variety the typical example is the lava of Catania, 1669. Plagioclase, augite, and olivine phenos predominate almost over the matrix of the same constituents in densely packed micro-aggregates. The brown vitreous base is subordinate; magnetite is sparsely disseminated.  $\text{SiO}_2$  48 per cent.

3. *Plagioclase Subordinate.*—These black lavas, in which augite and magnetite predominate, are relatively rare. The matrix is packed with magnetite grains, augite microliths, and micro-lamellar basic plagioclase. This variety occurs in the 1595 lava of Adernò and in the 1651 lava of Bronté.  $\text{SiO}_2$  47 per cent.

4. *Vitreous Lava.*—Wholly vitreous lavas are absent on Etna. A semi-vitreous variety occurs in the highly scoriaceous lavas or their glassy crusts; e.g. in that of Linguagrossa (1809); in Valle del Bove (1792), and in the Scoria Vacca (1651) lava flow near Mascali (east coast).  $\text{SiO}_2$  48 per cent.

V. *The Most Recent Lavas, 1883-1911.*—The chemical and mineralogical composition of these lavas agrees substantially with that of the older and oldest lavas. They are uniformly porphyritic basalts of dark-grey colour, composed of a matrix of predominant oligoclase and labradorite with anorthite, subordinate augite and olivine, with abundantly disseminated magnetite. The base is

semi-vitreous, of brown glass. The phenos are of the same minerals. These porphyritically developed elements are of first magmatic, or intratelluric consolidation, those of second or external consolidation are the microliths of the matrix. Of special interest are the largely metamorphosed sandstone, quartzite, and creta fragments which are embedded in the lava and ejected blocks of 1910, and were found also in the products of the 1892 and later eruptions. These enclosures are generally covered with a glassy sheath which separates them from the enveloping magma that tore them from the formations of the sedimentary platform through which the central chimney passes at a depth of 3,000 m. below the summit. The percentage of  $\text{SiO}_2$ , i.e. 48 to 49 per cent, in the lavas of the five eruptions from 1883 to 1911 has not changed; indeed, it is still the same as it was in the Catania lavas of 122 B.C. (49 per cent) and 1669 (48 per cent), previously mentioned.

VI. *Tuffs*.—These are of uniform composition, i.e. agglomerates of mineral débris, ash, lapilli, and scoria, cemented by calcareous, siliceous, and chloritic substances. Some Etnean tuffs are pale grey, often yellow, brown, brick-red (burnt), some whitish and some wholly black; according to the colour of the ejected ash from which they are mainly derived. Their last product of decomposition is a clay-like chloritic substance rich in oxide of iron. The formerly so-called Palagonite tuff (from Palagonia near Lake Lentini, 35 km. south-west of Catania) of Aci Castello is a brown, lucent aggregate of vitreous lapilli traversed by a tissue of zeolitic veins. The  $\text{SiO}_2$  percentage of Etnean tuffs and of the ashes is, like that of the lavas, 40 to 49 per cent.

VII. *Summary*.—As has been shown, the Etnean lavas, essentially basaltic, largely porphyritic, and wholly non-leucitic, have, from the earliest historic eruptions down to the present century, been derived from a remarkably uniform magma, in this respect like those of Vesuvius. The notably higher percentage of silica in the oldest Valle del Bove and associated lavas, up to 58 per cent, is not due to any essential difference of mineralogical composition either between them and the pre-Etnean coastal basalts or between them and the historic lavas of 47 to 49 per cent, but to the transformation of those lavas from an originally low basicity to that higher silica percentage by superincumbent pressure under high temperature. In the course of that transformation, the most basic elements, i.e. magnetite, magnesia, and olivine, gradually decomposed, the remaining more resistant felspathic constituents thus representing a higher percentage, while the colour of the lava gradually changed from dark grey to greenish by chloritic decomposition.

The following tables summarize the mineralogical composition and silica percentages of the different lavas described above, and also give the chemical composition of some of the typical lavas:—

TABLE OF THE MINERALOGICAL COMPOSITION OF ETNEAN LAVAS.

*e* = essential.*s* = subordinate.*a* = accessory.

Lava.	$\text{SiO}_2$ p.c.	Basic Plagioclase.	Augite.	Olivine.	Magnetite.	Adventitious.
I. Pre-Etnean Cliff Basalts.	47 to 49	<i>e</i>	<i>e</i>	<i>s</i>	<i>e</i>	apatite, zeolites.
II. Oldest Etnean (Valle del Bove) Lavas						
Augite-Andesites (Altered Basalts)	57	<i>e</i>	<i>e</i>	—	<i>a</i>	apatite.
Phonolitic Andesites	55	<i>e</i>	<i>s</i>	<i>s</i>	<i>e</i>	mica.
Green Andesites of Veins ,,	58	<i>e</i>	<i>e</i>	<i>a</i>	<i>e</i>	calcite, hornblende.
III. Oldest Terrace Lavas (Porphyritic Basalts)	49	<i>e</i>	<i>e</i>	<i>s</i>	<i>a</i>	apatite, hornblende.
IV. More Recent Lavas, Basalts—						
1. Plagioclase predominant . . .	49	<i>e</i>	<i>e</i>	<i>s</i>	<i>e</i>	
2. Plagioclase and Augite equal . .	48	<i>e</i>	<i>e</i>	<i>s</i>	<i>s</i>	
3. Augite and Magnetite pre-dominant . . .	47	<i>e</i>	<i>e</i>	<i>s</i>	<i>e</i>	
4. Semi-Vitreous (Scoriaceous) Lava	48	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	apatite.
V. Most Recent Lavas, 1883-1911 —						
Porphyritic Basalts (Augite-Olivine-Labradorites)	49	<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>	apatite.

TABLE OF THE CHEMICAL COMPOSITION OF ETNEAN LAVAS.

The following three typical analyses of the basalt (augite-olivine-labradorite) lavas of 122 B.C., 1669, and the mean of the lavas of 1883, 1886, 1892, 1908, and 1910, are given to show the remarkable uniformity of chemical composition during the last 2,000 years. The mean of the five analyses 1883-1910 corresponds almost exactly with the analysis of the lava of 1892.

	Mean of		
	Catania Lava, Catania Lava,		Lavas (5),
	122 B.C. <sup>1</sup>	1669. <sup>1</sup>	1883-1910. <sup>1</sup>
	Per cent.	Per cent.	Per cent.
$\text{SiO}_2$ . . .	49.17	48.10	49.00
$\text{Al}_2\text{O}_3$ . . .	15.91	21.61	18.07
FeO and $\text{Fe}_2\text{O}_3$ . . .	11.97	10.85	10.81
CaO . . .	10.26	8.82	9.71
MgO . . .	4.77	2.78	4.04
$\text{Na}_2\text{O}$ . . .	4.23	4.19	4.92
$\text{K}_2\text{O}$ . . .	2.23	4.05	1.39
		$\text{Ti}_2\text{O}_3$ 1.84	
	98.64	100.40	99.78
Sp. gr. . .	2.7	2.8	2.75

<sup>1</sup> The analyses of the lavas of 122 B.C. and 1669 are selected from among twenty-five given by v. Lasaulx of Etnean Lavas, op. cit. That of the five most recent lavas is the mean of the five corresponding analyses given by G. Ponte, op. cit.

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## THREE PHOTOGRAPHIC REPRODUCTIONS.

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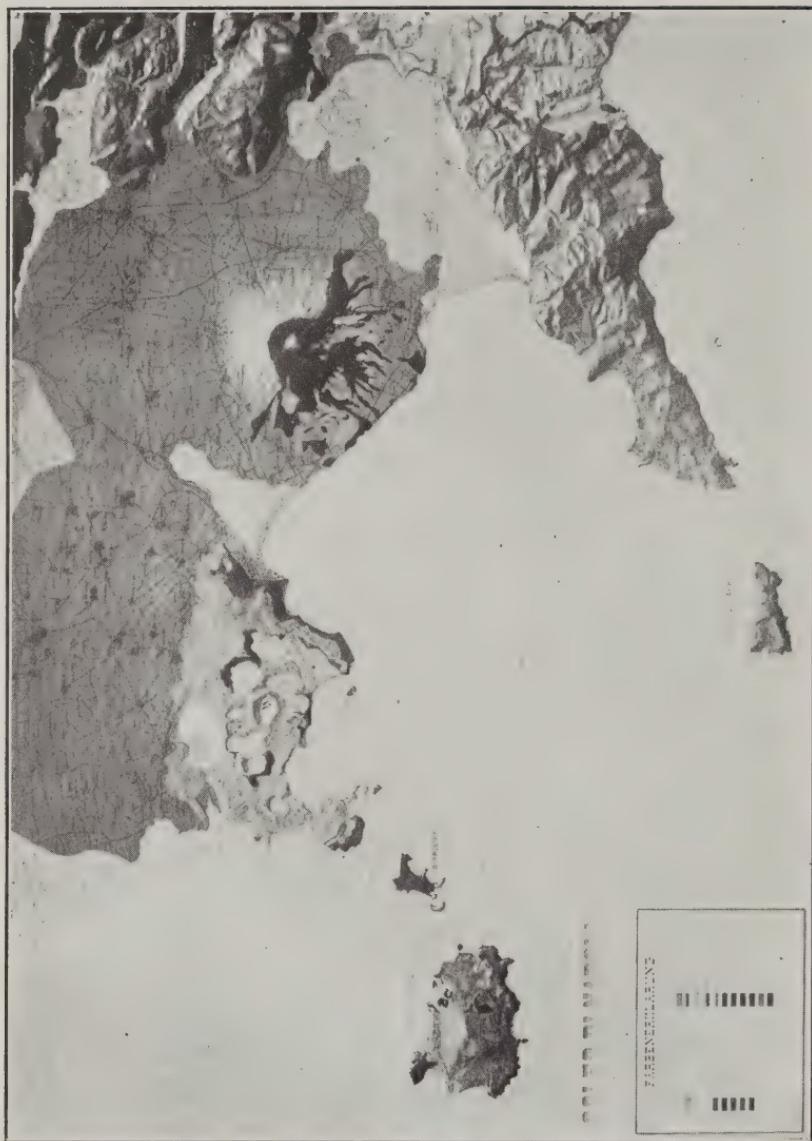
FIG. 16.—THE GULF OF NAPLES.

„ 17.—THE BAY OF POZZUOLI.

„ 18.—THE ISLAND OF ISCHIA.

## The Gulf of Naples.

Fig. 16.



On the right: The sedimentary spurs of the Apennines: i.e. the Sarno, Castellamare, and Sorrento Hills, and the island of Capri.

In the centre: The volcanic area of Somma-Vesuvius.

On the left: The volcanic area of Naples, the Phlegraean Fields, the Bay of Pozzuoli, and the islands of Procida, Vimara, and Ischia.

North of Vesuvius and the Phlegraean Fields: The dark-shaded great Cumpania tuff deposits of those volcanoes.

### The Bay of Pozzuoli.

Fig. 17.



*On the right : The volcanic area of Naples, Posilippo, and Nisido.*

*In the centre : The cones and craters of the Phlegræan Fields.*

*On the left : The promontory of Mte. di Procida, Miceno, and the islands of Procida and Vimara.*

*North of the Phlegræan Fields : The great Campania tuff plain.*

The Island of Ischia.

Fig. 18.



*In the centre:* The great cone and horseshoe crater of Epomeo. The black areas are lava streams; all the rest of the surface in white is yellow Epomeo tuff.

Figs. 16, 17, and 18 are reproduced from relief-maps by Signor A. Aureli,  
map-designer of the Royal Italian Geological Survey, Rome.









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